# Monitoring of Oceanic Feature Characteristic in Indonesia Strait Using SAR and Optical Image (Research Efforts on PHILEX Project)

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Grant Number: N00014-07-1-0422
http://frontier.tuis.ac.jp

## LONG-TERM GOALS

To understand the mechanism of physical and biological structure of waters over the Philippine Archipelagoes using satellite boarn synthetic aparutre radars and ocean color sensors.

We have concentrated our efforts to the water in the Philippine Archipelagoes instead of the originally proposed water in the Indonesian Archipelagoes, where the Philex (Philippines Straits Dynamics Experiment) project is undergoing.

## OBJECTIVES

1. To observe the physical structure over surface and in vertical response to winds and through flows using satellite observations, including the satellite boarn sysnthetic aparture radars and ocean color sensors.

2. To observe the biological contribution to the ocean surface using satellite observation and to discuss the mechanism of roughness observation.

3. To observe and understand the mechanism of oceanic phenomena in Philippine waters and relate large process that govern it.

## APPROACH

1. Physical structure of the water off Panay.

In June, 2007, a wind driven surface current along the Cuyo East Pass in the Philippine Archipelagoes (Fig.1) was observed by the Synthetic Aperture Radar (SAR) on the Advanced Land Observation Satellite (ALOS).

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **30 SEP 2008** | **Annual** | **00-00-2008 to 00-00-2008** |

| 4. TITLE AND SUBTITLE | 5a. CONTRACT NUMBER |
|---|---|
| **Monitoring Of Oceanic Feature Characteristic In Indonesia Strait Using SAR And Optical Image (Research Efforts On PHILEX Project)** | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Tokyo University of Information Sciences,4-1, Onaridai, Wakaba, Chiba, Japan 265-8501,** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**code 1 only**

14. ABSTRACT
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15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **Same as Report (SAR)** | **44** | |

Simultaneously, the moored Acoustic Doppler Current Profiler (ADCP) at the west of the Panay Island observed the northward current in the surface to 150 m depth from the middle of June to the beginning of July, 2007, while the East-North-East or East wind was dominant.

The MODerate resolution Imaging Spectroradiometer (MODIS) on the AQUA observed the decrease of the sea surface temperature and the increase of chlorophyll-a concentration. The satellite observations provided the horizontal response of the primary production and the ADCP provide the time series of the vertical distribution of water mass.

This study examined the mechanism of the primary production in the Philippine Archipelagoes based on these observations and from the point of response of biological activities to the environmental changes, which could be determined by the seasonal winds.


***Fig. 1 Region of Interest in the Philippine Archipelagoes***

2. Biological contribution to the water surface.

In February of 2008, we jointly conducted the in-situ measurement off the Panay Island with Prof. Cesar Villanoy and his colleges of the Philippine University to investigate a biological contribution to the ocean surface.

In the in-situ measurement, CTD profilings were conducted to get the vertical profiles of temperature, salinity and photosynthetically available radiation as a function of depth. Also, the waters from the surface and layers up to 150 m were sampled by the Niskin bottle to get the chlorophyll-a, nitrate, nitrite, phosphate, and silicate concentration.

The surface roughness was observed by the synthetic aperture radar (SAR) on the ENVISAT. The chlorophyll-a concentration and sea surface temperature distribution were observed by the MODIS on the Terra and Aqua. Also, the wind distribution data from the National Centers for Environmental

Prediction (NCEP) / the University Corporation for Atmospheric Research (UCAR) were applied over the satellite data to understand the contribution of wind.

3. Mechanism of oceanic phenomena.

The oceanic features can be detected in SAR and visible and near infrared (VNIR) image data through dampening effect of small capillary Bragg waves, which affect radar backscattering and changes the sun illumination. Bragg scattering is a resonant interaction of radio waves the 1-3 cm capillary waves (Maul, 1995). Oil slick on the water surface dampens these waves, and since the wavelength of these ocean waves is comparable to that of different radar wavelength, the absence of sea clutter resulting from damping of these waves by oil slicks shall be observable as dark region in the radar images. On the other hand, internal waves are visible in SAR and optical image because they modulates sea surface, causes a low linear bulge at surface, accompanied by distinctive pattern of small-scale surface waves with high circulation cell at the trailing edge of an internal wave resulting as dark and bright strips on uniform background in image (Alpers, 1985, Sabin, 1996).

Similar surface signatures of surface waves, wind signatures, oceanic fronts and mesoscale eddies, also can be observed in SAR and optical images, because they are associated with a variable surface current which modulates the sea surface roughness and affect radar backscatters or sun glittering. Thus, oceanic feature can be detected through the data content in image, which can be vary according to remote sensing sensors platforms and sensors, for example the information of backscattering from SAR image or the spectral reflectance from visible image.

**WORK COMPLETED**

1. Physical structure of the water off Panay

Dr. Janet Sprintall of the Scripps Institutions of Oceanography, member of Phillex project, deployed the mooring Acoustic Doppler Current Profiler (ADCP) at five stations in the Philippine Archipelagoes to monitor local currents in the Philippines Straits Dynamics Experiment (PhilEx) program. The mooring system off the Panay west coast was deployed and operated for about one month June of 2007.

Fig. 2-a and 2-b show the zonal and meridional component of current along the water column (y-axis) vs date (x-axis) observed by ADCP off the Panay in June of 2007. Fig. 2-b shows a significant change in the meridional components around June 20, although the zonal component didn't show a remarkable change (Fig. 2-a). The north ward surface current has started from June 21 based as a result of the beginning of eatery and the Ekman current.

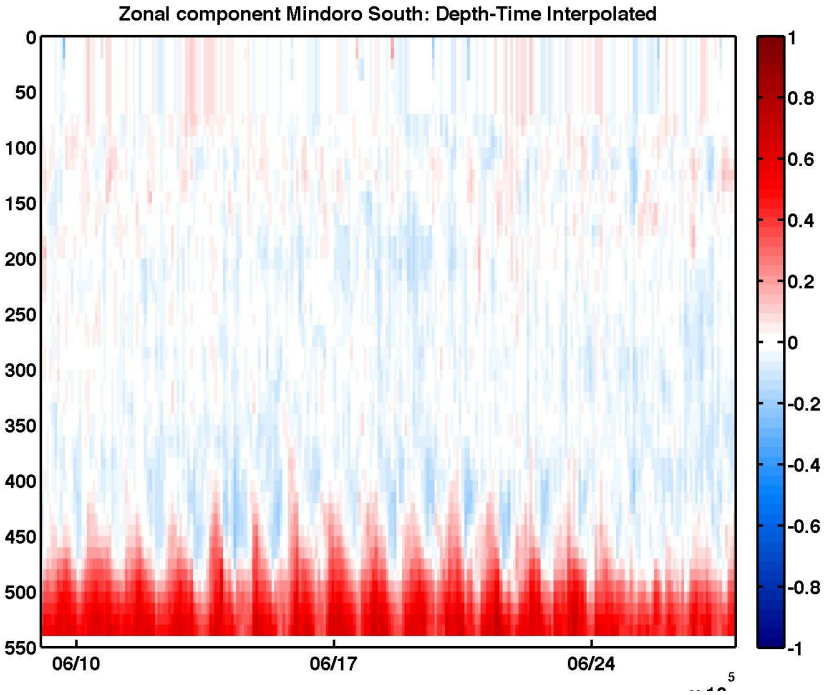


*Fig. 2-a Zonal component observed by ADCP off the Panay Island.*

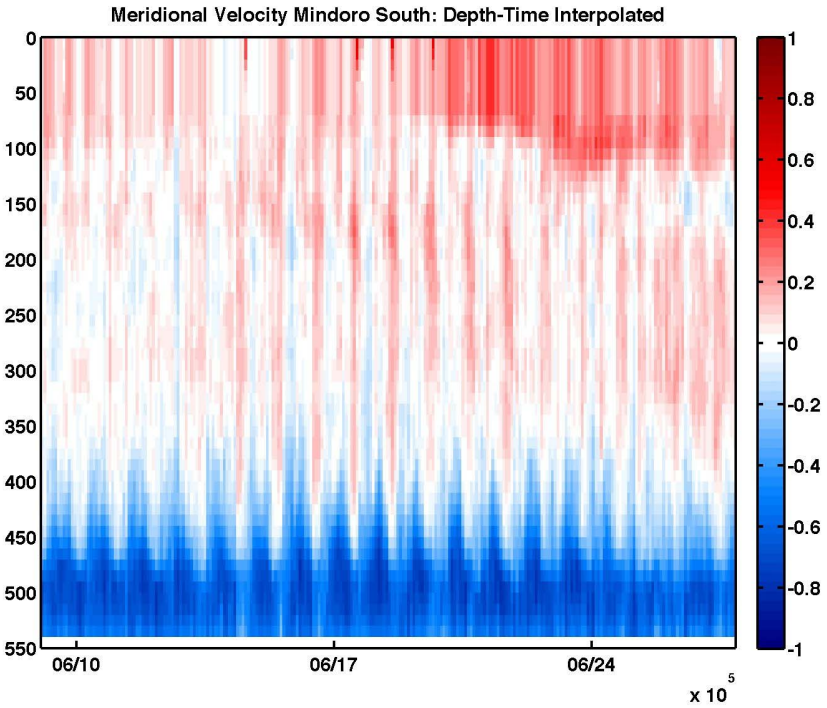


*Fig. 2-b Zonal component observed by ADCP off the Panay Island.*

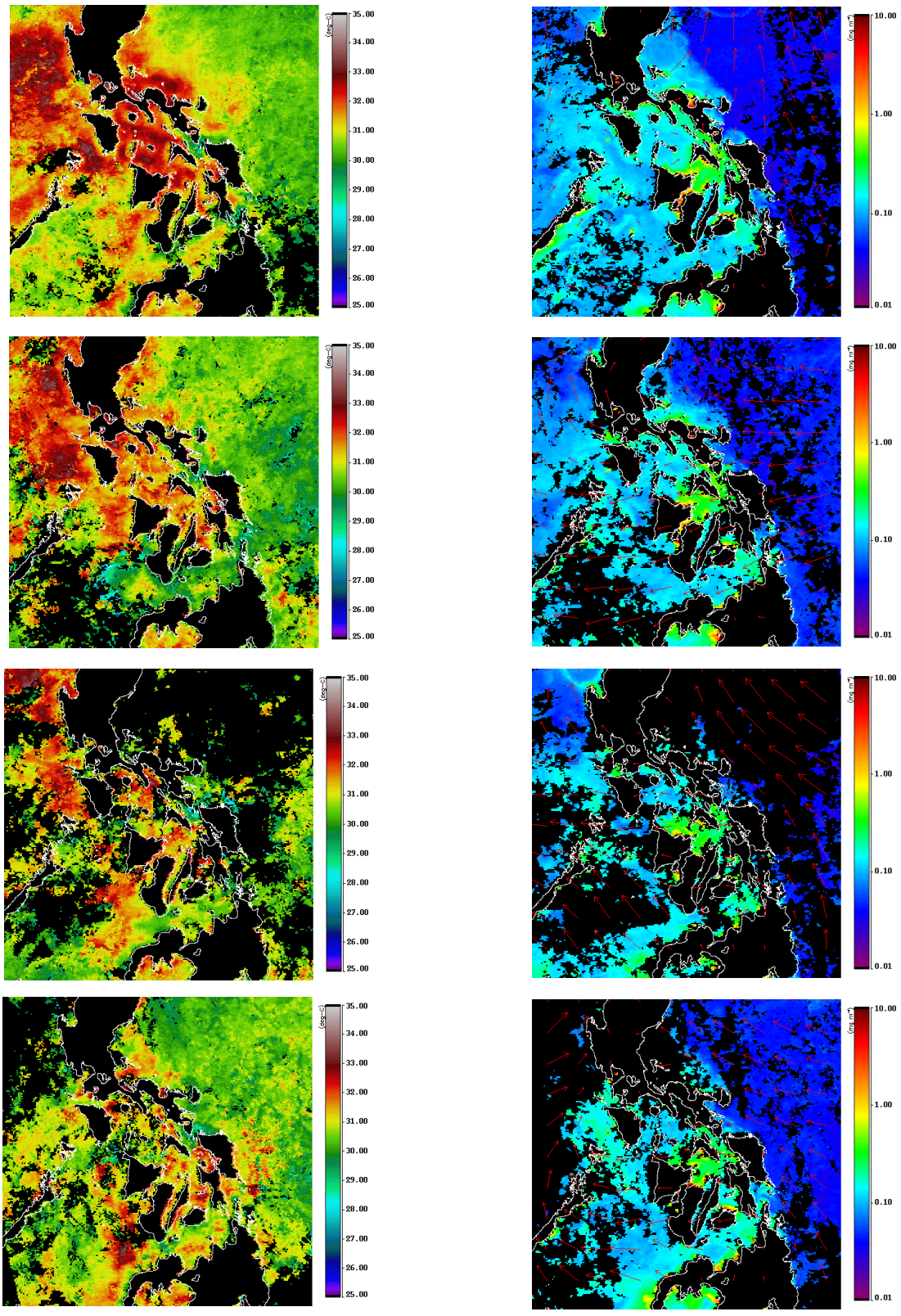


***Fig. 3 Sea surface temperature (left) and chlorophyll-a (right) with wind vectors a & b : from 2007.06.02 to 06.09, c & d : from 2007.06.10 to 06.17, e & f : from 2007.06.18 to 06.25, g & h : from 2007.06.26 to 07.03***

Fig. 3 a to h show a 8 days composite of the sea surface temperature and chlorophyll-a distribution over the Philippine Archipelagoes observed by MODIS in June 2007. From June 2 to 9, 2007, the South wind was dominant along the eastern side of Philippine Archipelagoes and the wind speed was low in the Sulu Sea. The sea surface temperature was very high and the standing stock of phytoplankton was low in the Sulu Sea. From June 10, the wind field has significantly changed to the East wind through over the Philippine Archipelagoes, although the wind field along the eastern side has changed to the South-West wind. The western off of the Panay Island exhibited the temperature decrease to the end of June 2007.

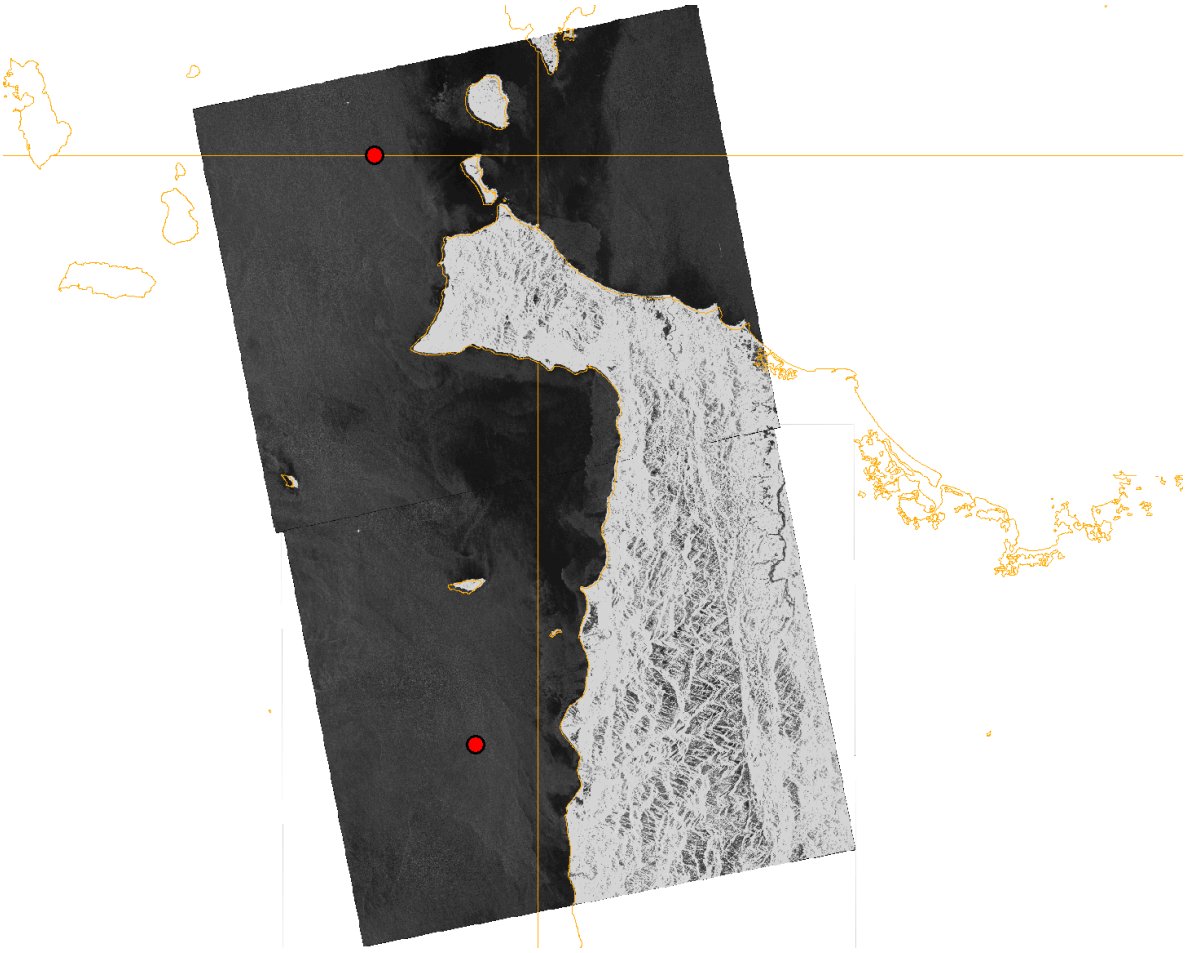

***Fig.4 Surface roughness observed by PALSAR on June 21, 2007***

Fig.4 shows the surface roughness observed by the Phased Array type L-band Synthetic Aperture Radar (PALSAR) on the Advanced Land Observing Satellite (ALOS) observed the sea surface roughness along the Cuyo East Passage on June 21 of 2007. The PALSAR reproduced the NNW current and upwelling in the northern side of islands.

The reanalysis data of surface wind provided by the National Centers for Environmental Prediction (NCEP) showed the development of East-North-East or East wind from the middle of June, 2007.

From these measurements, we could estimate that the north-ward current from the middle of June 2007 is the Ekman current generated by the East wind. The north-ward current could carry the water from the Sulu Sea.

2. Biological contribution to the water surface

2-1 Background measurement

Dr. Janet Sprintall provided us the record of ADCP measurements at stations in the Philippine Archipelagoes. Fig.5 shows the chlorophyll-a distribution, wind speed and direction, and ADCP zonal and meridional measurements at the South Mindoro (the Cuyo East Pass on Fig.1). At this station, there was a drastic change from September 2007 with the entrainments of SE-ward currents between 200 and 400 m in depth. In contrast, the surface water around 50 m showed the NE or NW-ward current.

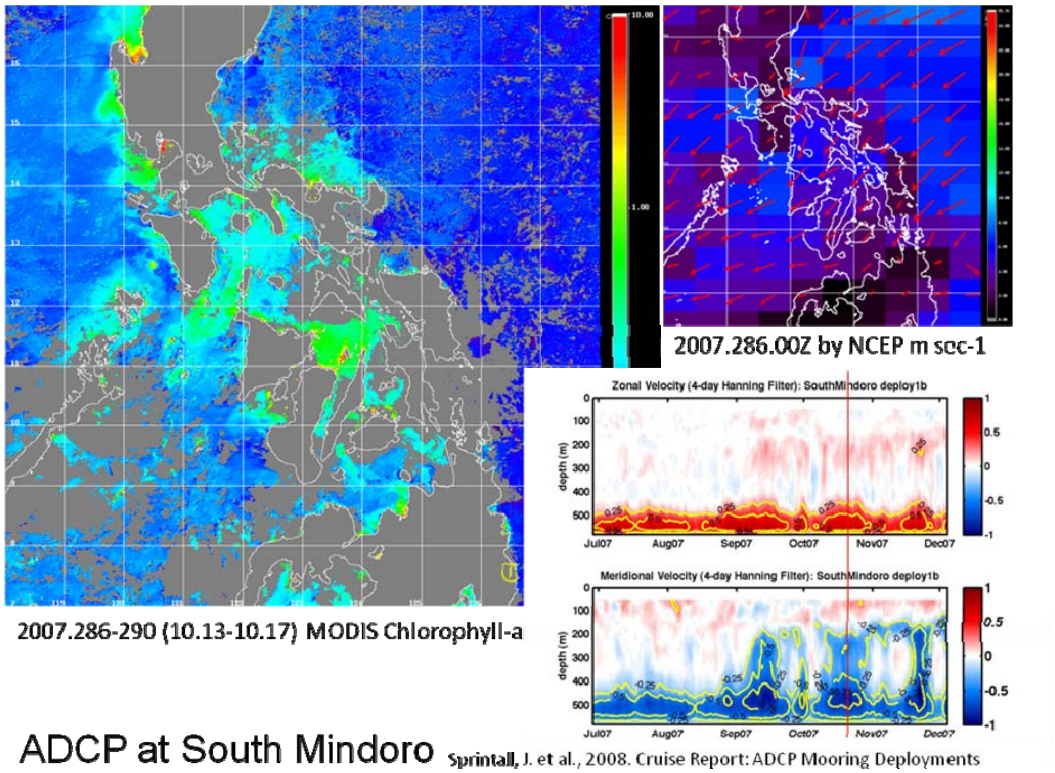


***Fig.5 Composite of the chlorophyll-a distribution observed by MODIS from Oct.13 – 17, 2007 (left), Wind speed and direction by NCEP on Oct.13, 2007 (right top), and ADCP measurement in zonal and meridional component(right bottom).***

According to the composite image of chlorophyll-a concentration observed by MODIS from Oct. 13 to 17, 2007, the water at the northern end of the Sulu Sea, including the water at the Mindro Strait and the Tablas strait, exhibited a higher chlorophyll-a concentration relative to the major water in the Sulu Sea. The water in the western off of the Panay Island showed a lower chlorophyll-a concentration as well as the major water in the Sulu Sea. The dominant wind field in this region was NE wind in this season.

The currents observed by ADCP could be driven by the wind, especially a seasonal wind from NE or SW wind will determine the current in the surface layer, and the pressure gradients within the archipelagoes or between the Pacific and the South China Sea..

2-2. In-situ measurement off Panay

In February, 2008, we conducted the in-situ measurement in the western off of the Panay Island jointly with Prof. Cesar Villanoy, the University of Philippine and a member of Philex program to obtain in-situ synchronous to satellite measurements. Our objectives were to discuss a contribution of biological film to surface roughness observed by SAR.

Fig. 6 shows a vertical profile of temperature and salinity at the St. A, where the ADCP is moored by Dr. Janet Sprintall, and at the St. B, which is positioned at the center between St. A and the west coast of Panay. In this expedition, the CTD was deployed to 140 m in depth with the cable length of 150 m, which is the maximum depth of phytoplankton being observed. The temperature and salinity profiles at St. A show a vertical mixing from the surface to 40 m, while the NE wind was strong in the day time and calm in the night. In contrast, St. B showed the stratification of temperature.

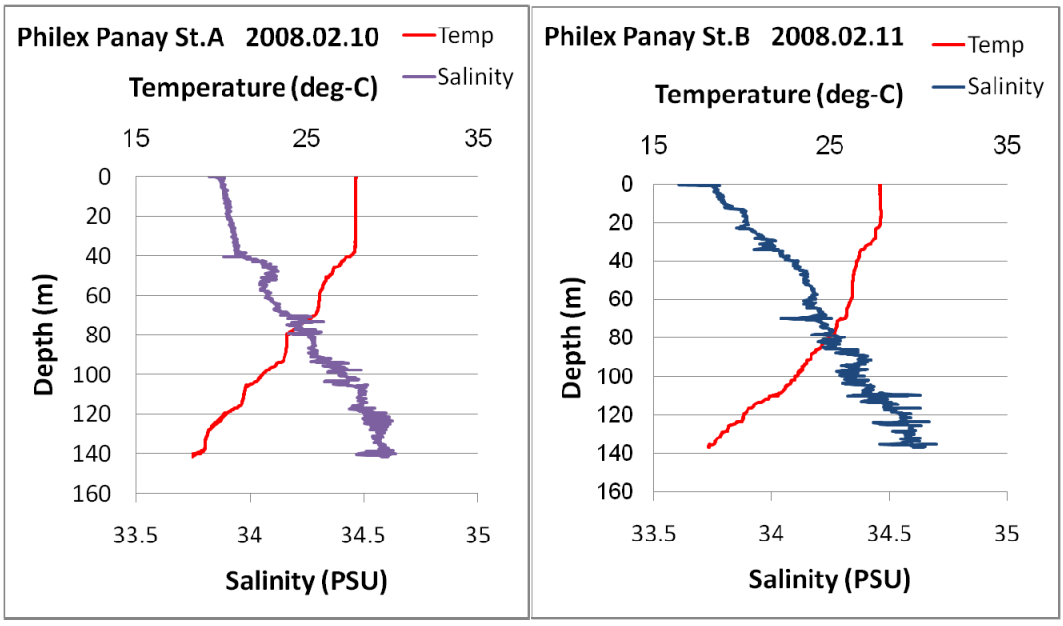


***Fig. 6. Vertical profiles of temperature and salinity off the west coast of the Panay Island. St.A (left), where ADCP moored. St.B (right) at the center between St.A and coast.***

Fig. 7 shows the sea surface roughness observed by the SAR on ENVISAT and the wind distribution by NCEP on Feb. 7, 2008 in advance to our in-situ measurement. The NE wind around 8 to 9 m sec-1 were dominant and the SAR image exhibited a bright region along the wind direction. The slightly dark regions were observed between St. A and the west coast of the Panay Island, which is marked on the SAR image.

In Fig. 4, we could observe the patterns of the surface roughness corresponding to the north-ward current, which might be suggested as the Ekman current. In contrast, it is difficult to observe the surface roughness which is different from the wind direction in Fig. 7. It is suggested that the strong wind and wind generated surface roughness veiled the surface pattern corresponding to the current.

Fig. 8 shows the vertical profiles of nutrients, including NO3, SiO4, PO4, and chlorophyll-a concentration at St. A and at the center between St. A and the west coast of the Panay Island on Feb. 10 and 11, 2008. Although it was difficult to distinguish the difference of water bodies by temperature and salinity, the vertical profile of silicate at St. B was depleted to 140 m and the vertical profile of nitrate exhibited a slightly lower concentration at St. B. The vertical profiles of chlorophyll-a concentration at St. A showed a higher concentration in all depth relative to St. B. These nutrients and chlorophyll-a profiles suggest that there are two different type of water mass.

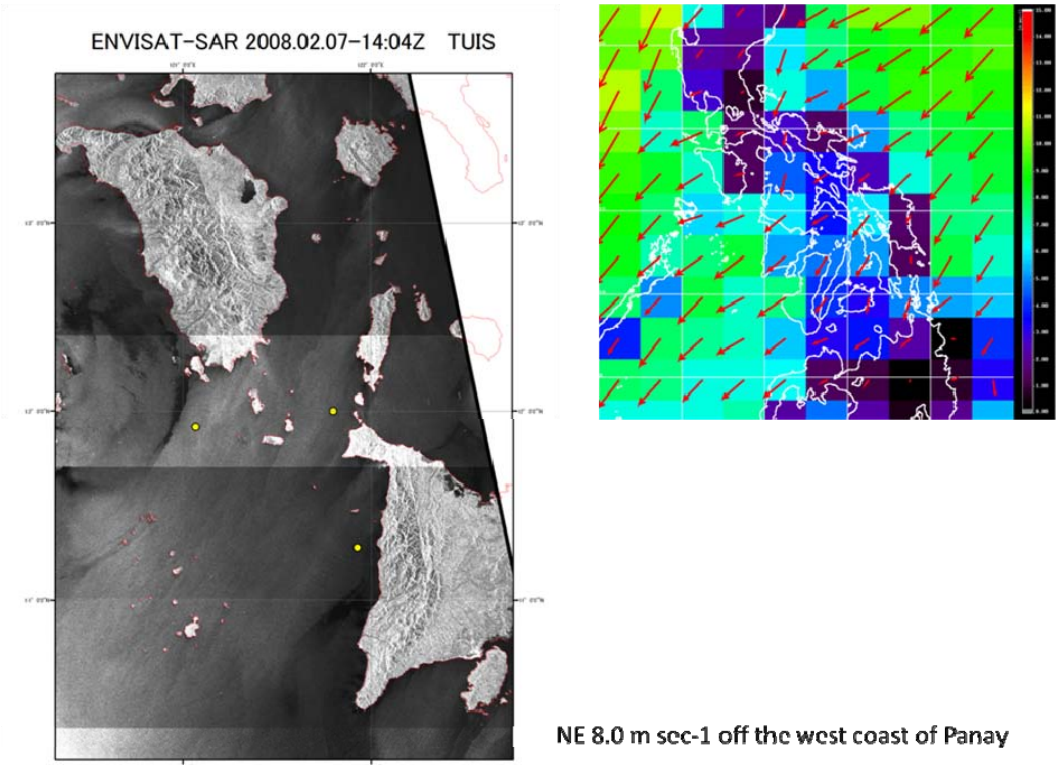


***Fig. 7. Sea surface roughness observed by SAR and NCEP wind distribution on Feb. 07, 2008.***

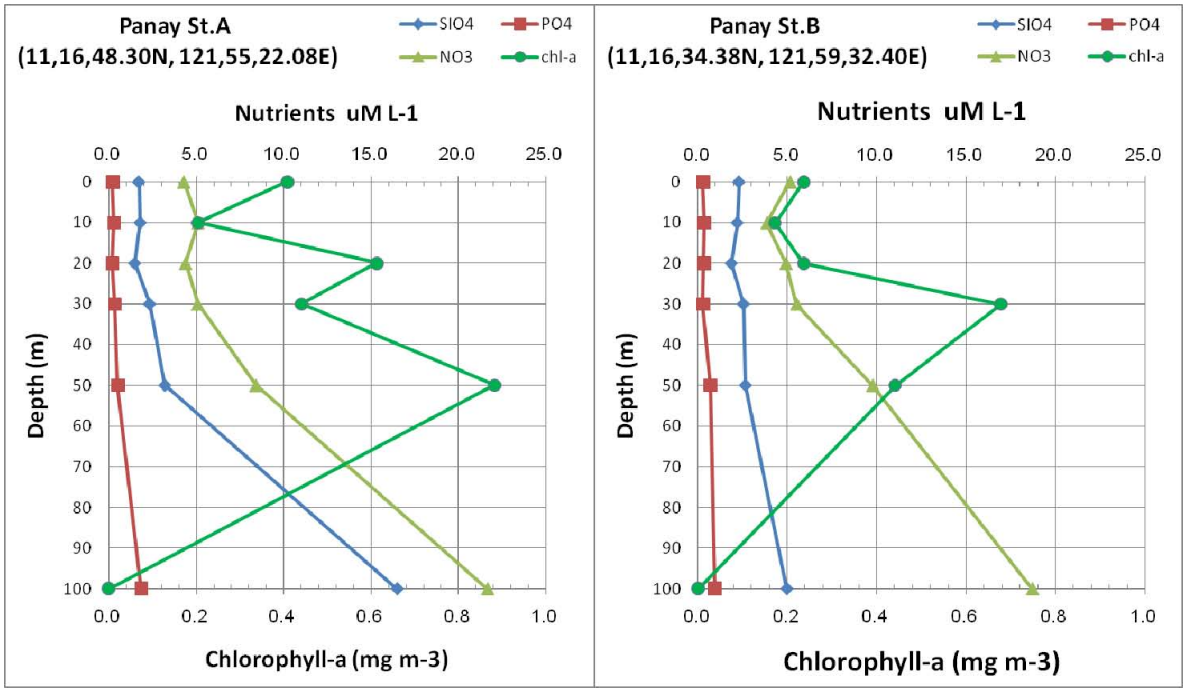


***Fig. 8. Vertical profiles of nutrients, NO3, SiO4, PO4, and Chl-a at St. A and B in Feb, 10 (left) and 11 (right), 2007.***

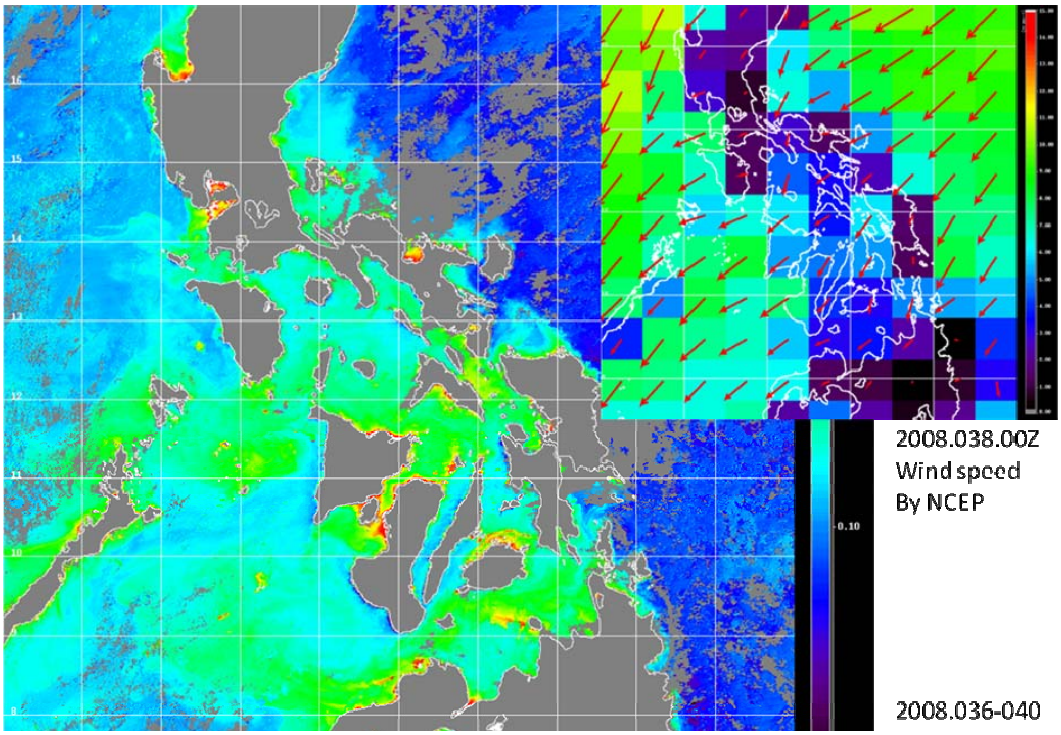


***Fig. 9. Chlorophyll-a distribution observed by MODIS and NCEP wind distribution on Feb. 5, 2008.***

According to Fig. 9, it is possible to distinguish the water body of a higher concentration of chlorophyll-a in the western off of the Panay Island. Also, there is a water body which is intruding to the western coast of the Panay Island from the Sulu Sea.

From the nutrients measurement and chlorophyll-a distribution, the water from the Sibuyan Sea with a higher concentration of the nutrients entrained into the northern part of the Sulu with the NE wind and generated the higher chlorophyll-a water. The water from the central part of the Sulu sea with a depleted water intruded into the western coast of the Panay Island.

3. Mechanism of oceanic phenomena

Oceanic features in Philippine waters have been observed using 29 images of PALSAR SAR and AVNIR image data during February – December 2007 period. Chlorophyll-a distribution has been retrieved using MODIS data. Ocean condition, such as current direction, geostrophic velocity, wave height and wind speed over study area were observed using SSALTO DUACS Products @CNES, CLS. ADCP data taken from Phil-Ex Join Philippines-USA Cruise is used to analyze the oceanic feature mechanism.

The observation has been done over 3 study areas as follows,

3-1. Mindoro – Panay Strait

3-1-1. ALOS PALSAR Image:

a. Date: 28 May 2007, Time: 02:15:17 UTC, Location: Southwest Coast of Mindoro Island.

Observed oceanic features were rain patches and natural film at south west coast of Mindoro Island. Weather and ocean condition were unfavorable for oceanic feature observation. Currents direction was on west and northwestward direction. Wind speed about 3.8-4 m/s. Wave height about 0.6-0.7 m.

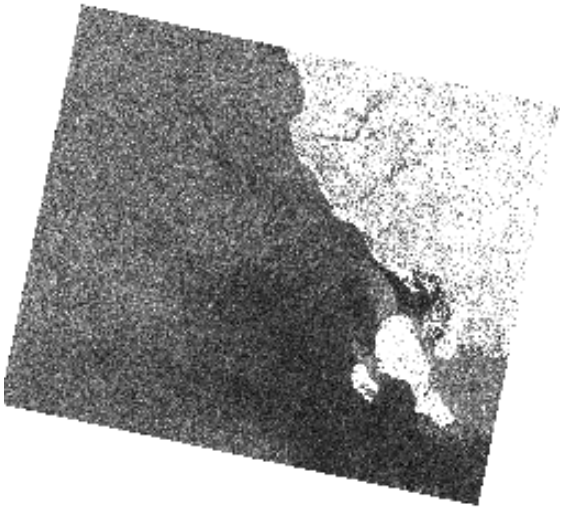

***Fig.10. ALOS PALSAR Image over south west coast of Mindoro Island (Date: 2007/05/28, Time: 02:15:17 UTC).***

b. Date: 28 May 2007, Time: 02:15:25 UTC, Location: South Coast of Mindoro Island.

Observed oceanic features were rain patches (middle left and upper right part of image). Weather and ocean condition were unfavorable for oceanic feature detection. Current direction was on northwest and westward direction. Wind speed about 3.8-4.2 m/s. Wave height about 0.55-0.65 m.

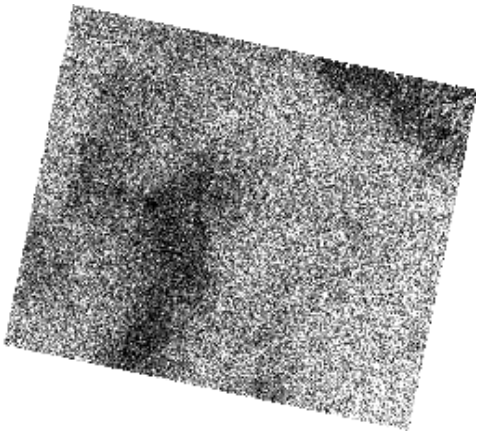

***Fig.11. ALOS PALSAR Image over south coast of Mindoro Island (Date: 2007/05/28, Time: 02:15:25 UTC)***

c.Date: 14 June 2007, Time: 02:17:24 UTC, Location: Coast off Mindoro and Luzon Island.

Oil slicks and natural films were detected at east and west coast of Mindoro Island. Wind shear area is observed at south of Mindoro Island. Packets of non linier internal wave (NLIW) propagated on northwest direction have been observed in Lamon Bay, east of Luzon and Ragay Gulf, south of Luzon. Dark feature possibly due to heavy rain marked by bright pixels at border has been observed at northwest coast of Panay Island. Dark patch of low wind area covered by island were observed at Mindoro Strait, and coast off Luzon Island. Oceanic condition during image observation was favorable to observe oceanic feature. Current direction on southeast and southward direction, wind speed about 3-3.2 m/s, and wave height about 0.5 m.

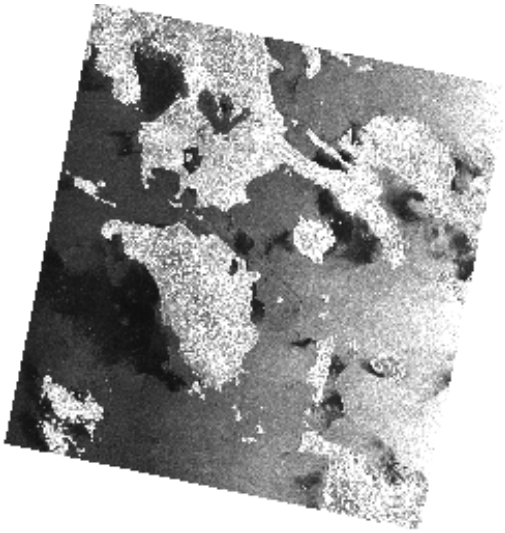

***Fig.12. ALOS PALSAR Image over coast of Mindoro Island (Date: 2007/06/14, Time: 02:17:24 UTC)***

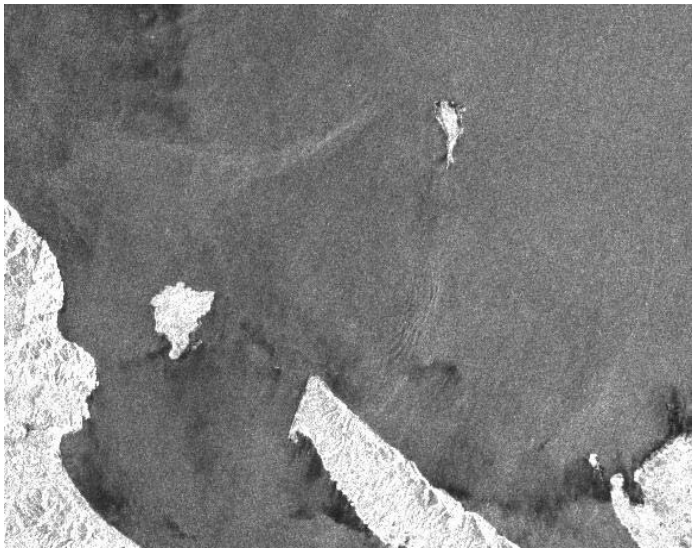

***Fig.13-a. Packets of non linier internal waves at Lamon Bay, east of Luzon (Date: 2007/06/14, Time: 02:17:24 UTC).***

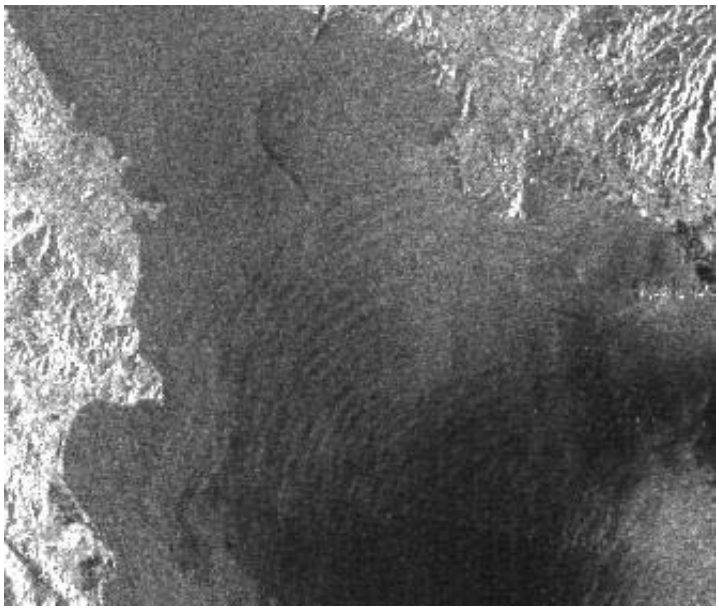

***Fig.13-b. Non linier internal waves at Ragay Gulf, south of Luzon (Date: 2007/06/14, Time: 02:17:24 UTC).***

d. Image date: 14 June 2007, Time: 02:16:43 UTC, Location: South Coast of Mindoro Island.

Observed oceanic features were NLIW propagated on southeast direction at northeast coast of Palawan Island, natural film at east coast of Palawan Island and west of Mindoro Island, oil slicks at Mindoro Strait and west coast of Iloilo, dark feature of rain patches at west coast of Panay and east of Mindoro Island, and dark patch of low wind area covered by island at northwest of Negros. Ocean condition during image observation was favorable for oceanic feature detection. Currents directions were on southeast and southward direction. Wind speed about 3-3.2 m/s. Wave height about 0.5 m.

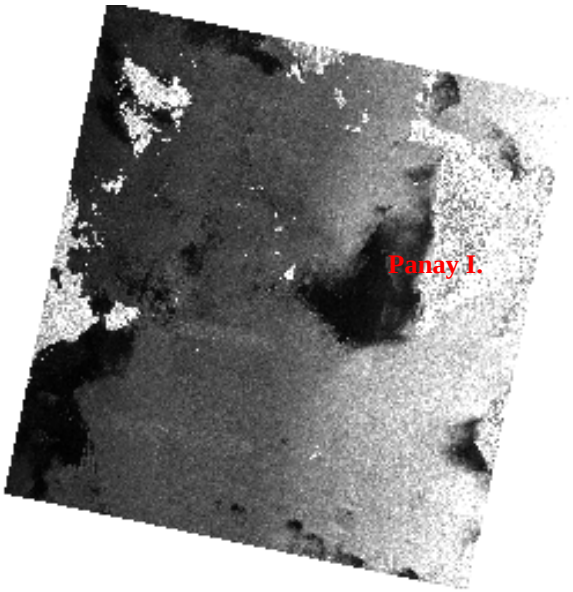


***Fig.14. ALOS PALSAR Image over south coast of Mindoro Island (Date: 2007/06/14, Time: 02:16:43 UTC).***

e. Image date: 14 September 2007, Time: 02:17:10 UTC, Location: South Coast of Mindoro Island.

Observed oceanic features were NLIWs on eastward direction at northeast coast of Palawan Island, oil slicks and natural films at Mindoro Strait, rain patches at north coast of Panay Island. Ocean condition was favorable for oceanic feature observation. Current direction was on southeast and southward direction. Wind speed about 4-6 m/s. Wave height about 0.9-1 m.

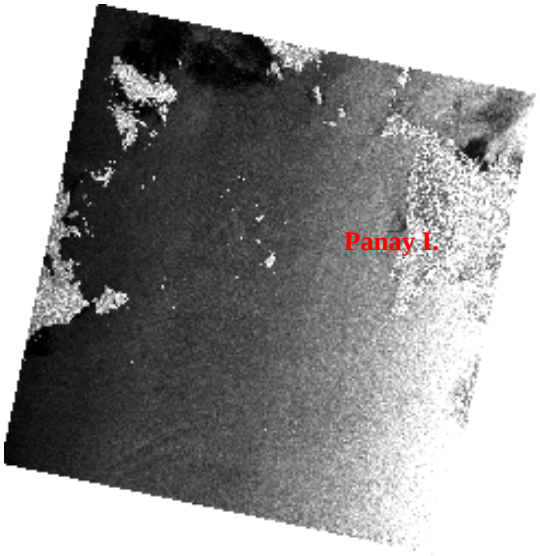


***Fig.15. ALOS PALSAR Image over south coast of Mindoro Island (Date: 2007/09/14, Time: 02:17:10 UTC).***

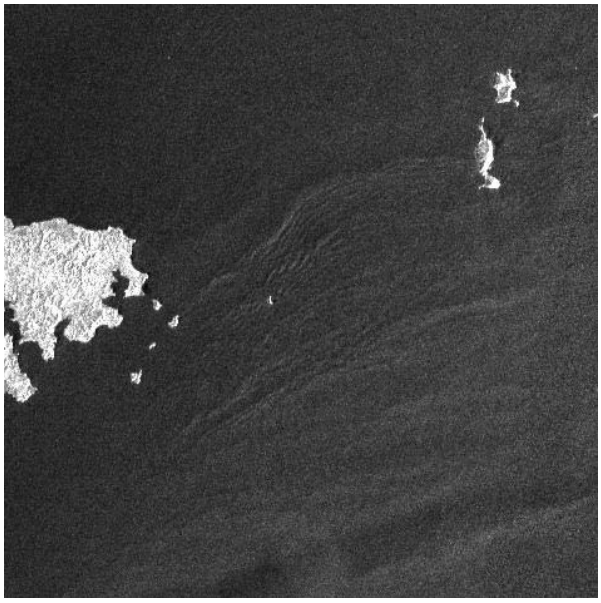

***Fig.16. Non linier internal waves at northeast coast of Palawan Island (Date: 2007/09/14, Time: 02:17:10 UTC)***

f. Date: 6 November 2007, Time: 14:32:42 UTC, Location: North Coast of Panay Island.

Image observation shows no obvious oceanic feature. Weather and ocean condition were possibly strong wind and high waves marked by random black and white pixels. Current direction was on westward direction. Wind speed about 2-4 m/s. Wave height about 1.2-1.6 m.

***Fig.17. ALOS PALSAR Image over north coast Panay Island (Date: 2007/11/06, Time: 14:32:42 UTC).***

g. Date: 25 November 2006, Time:  02:14:48 UTC, Location: Southwest Coast of Mindoro Island.

Image observation shows no obvious oceanic feature. Weather and ocean condition were unfavorable for oceanic feature observation possibly due to strong winds. Current direction was on south and southeastward direction. Wind speed about 3.6-4 m/s. Wave height about 0.8-1 m.

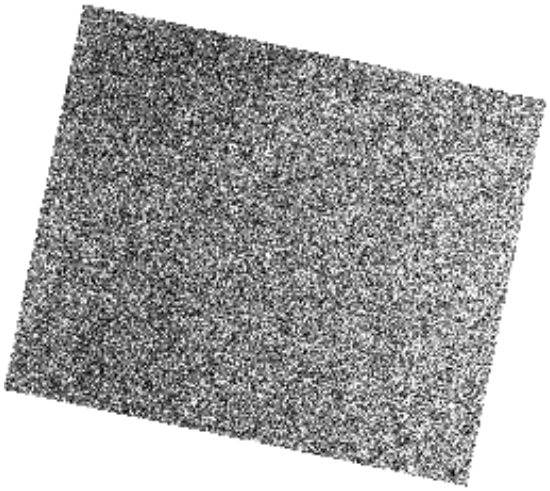

***Fig.18. ALOS PALSAR Image over South west coast of Mindoro Island (Date: 2006/11/25, Time: 02:14:48 UTC).***

h. Date: 20 December 2006, Time: 15:08:03 UTC, Location: Northwest Coast of Panay Island.

Observed oceanic features were rain patches at northwest coast of Panay Island, strike lines of wave front, and low wind area covered by island at west coast of Panay Island.

Ocean condition was unfavorable for oceanic feature observation. Currents direction was on southwestward direction. Wind speed about 9-10 m/s. Wave height about 2-2.2 m.

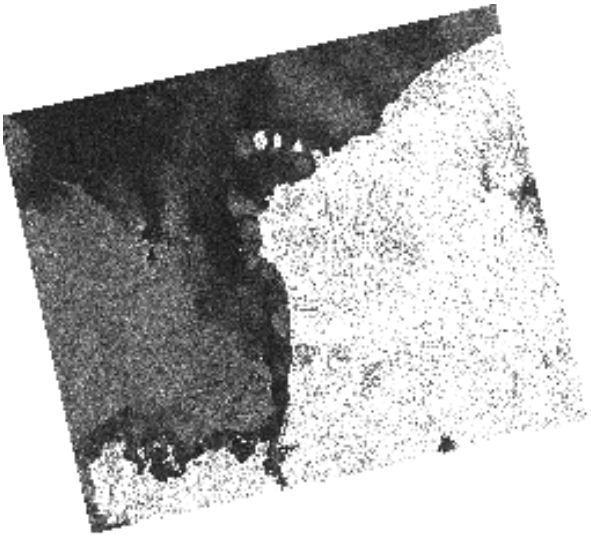

***Fig.19. ALOS PALSAR Image over northwest coast of Panay Island (Date: 2006/12/20, Time: 15:08:03 UTC).***

3-1-2. ALOS AVNIR-2 Image

a. Date: 23 February 2007, Location: South Coast of Mindoro Island.

Observed oceanic features were natural film and wind shear feature at west coast of San Jose (left part of image), front at south west coast area (upper left part of image) and south coast of San Jose (middle

part of image), and packet of internal waves propagated on southeastward direction at west coast of San Jose (left part of image). Ocean condition was favorable for oceanic feature detection. Current direction was on northeast and eastward direction at west coast of Mindoro Island, and southeast ward direction at west coast of Panay Island. Wind speed about 3.4-3.8 m/s. Wave height about 0.6-0.7 m.

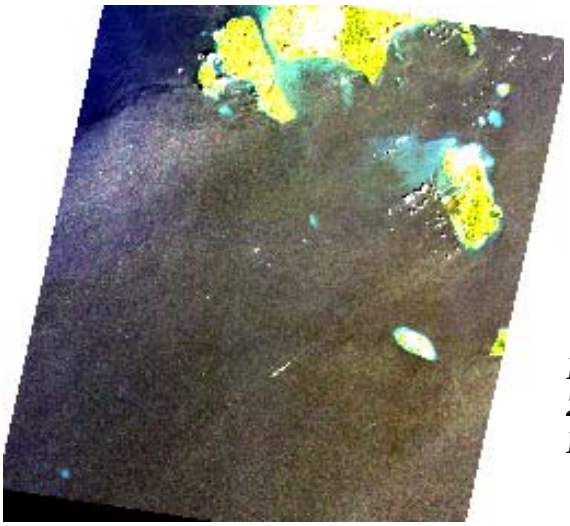

***Fig.20. ALOS AVNIR-2 Image on 2007/02/23 over South of Mindoro Island***

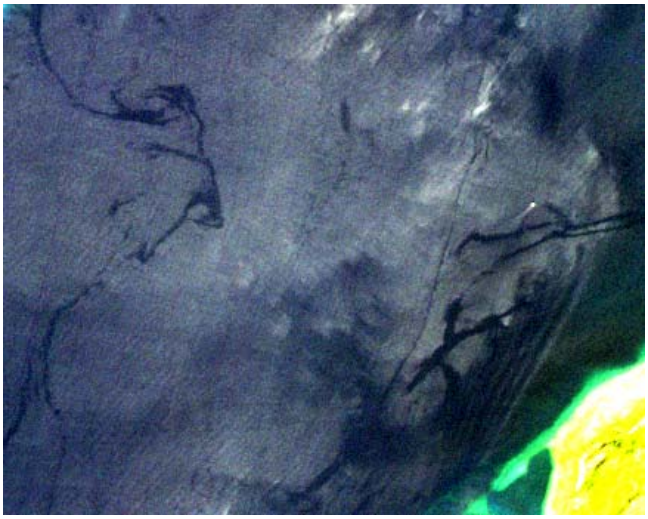

***Fig.21-a. Natural films and a packet of internal waves at west coast of San Jose, Mindoro Island (upper left of view image, date: 2007/02/23)***

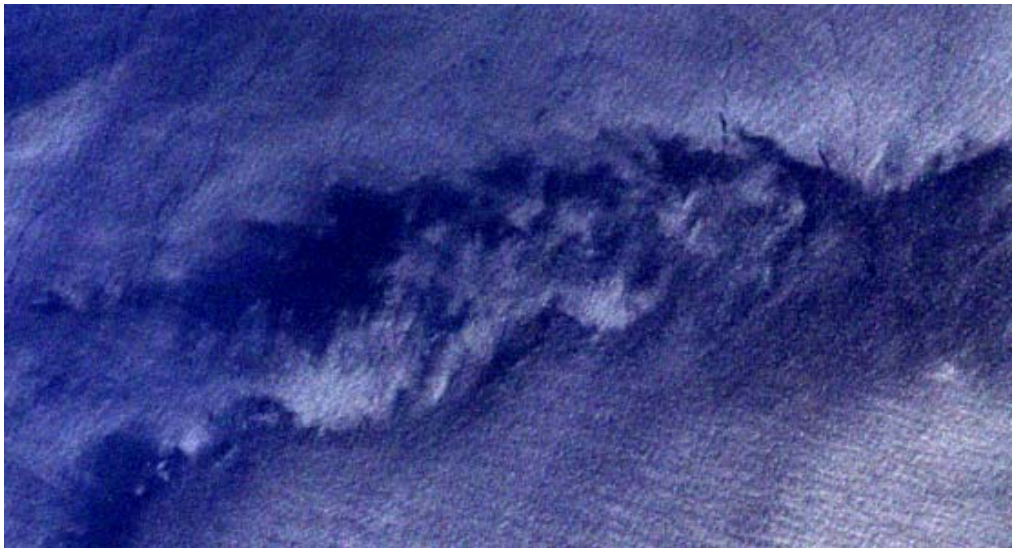

***Fig.21-b. Wind shear feature at south west coast area of San Jose, Mindoro Island (upper left part of view image, date: 2007/02/23)***

***Fig.21-c. Internal waves at south coast of Mindoro Island (middle right of view image, date: 2007/02/23)***

b. Date: 26 May 2007, Location: South Coast of Mindoro Island.

Observed oceanic feature were natural film at west coast of San Jose (upper left part of image) and south coast of Mindoro Island (middle left), and wave fronts on westward direction. Ocean condition was favorable for oceanic feature observation. Current direction was on southwest direction (at northern part) and northwestward direction (at southern part). Wind speed about 1.5-2 m/s. Wave height about 0.3-0.4 m.

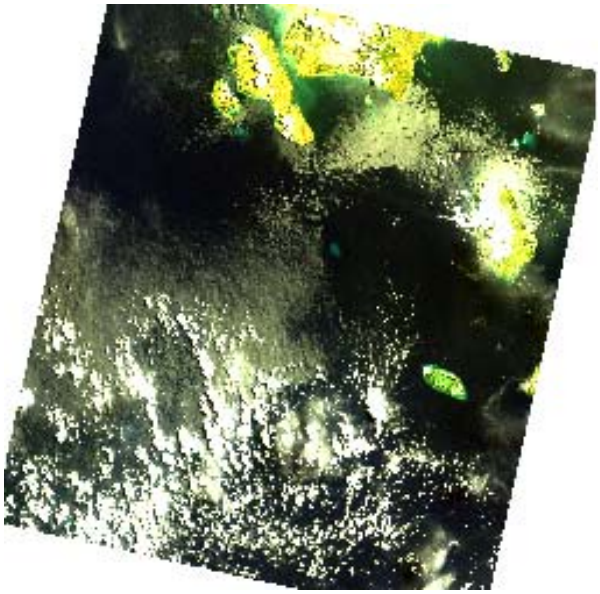

***Fig.22. ALOS AVNIR-2 Image on 2007/05/26, over South coast of Mindoro Island.***

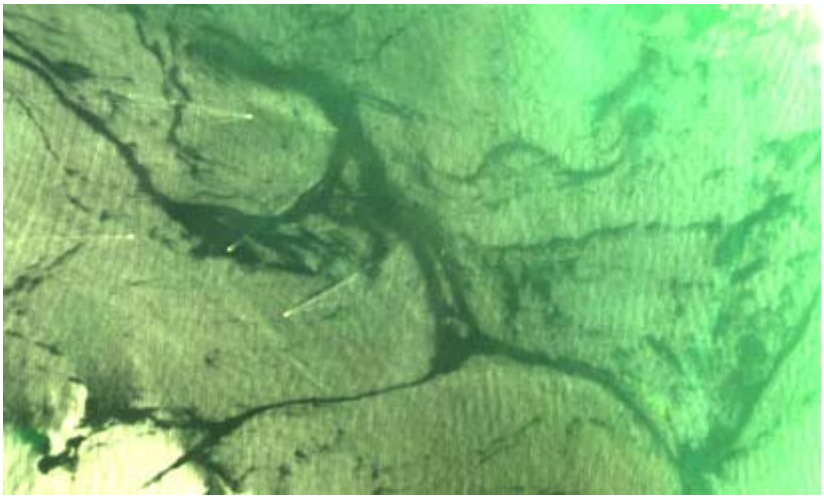

***Fig.24. Eddy associated with natural film at west coast of San Jose (upper left part of view image, date: 2007/05/26)***

c. Date: 9 November 2007, Location: South Coast of Mindoro Island.

Observed oceanic features were oil slicks and natural films at Mindoro Strait, eddies feature associated by slicks at northwest coast of Panay Island. Wave fronts were moving into southwestward direction. Oceanic condition was favorable for oceanic features observation. Current direction was on southwest and northwestward direction. Winds speed was about 2.6-2.8 m/s. Wave height was about 1-1.2 m.

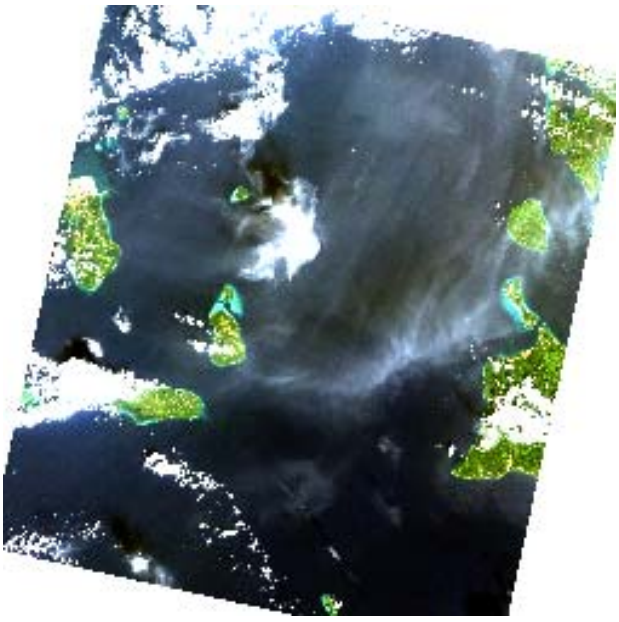

***Fig.25. ALOS AVNIR-2 on 2007/11/09 over south coast of Mindoro Island.***

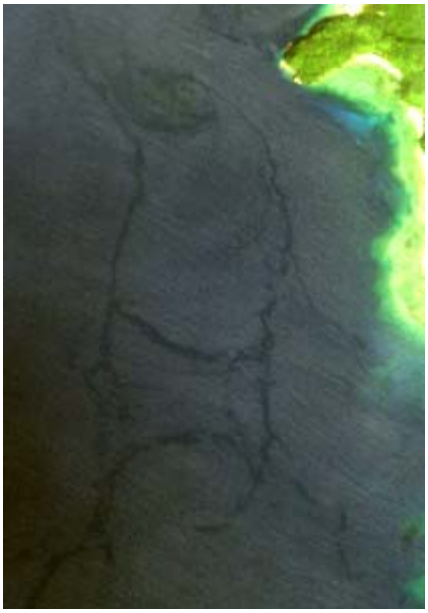

***Fig.26-a. Eddy features associated with slicks at northwest coast of Panay Island (Date: 2007/11/09)***

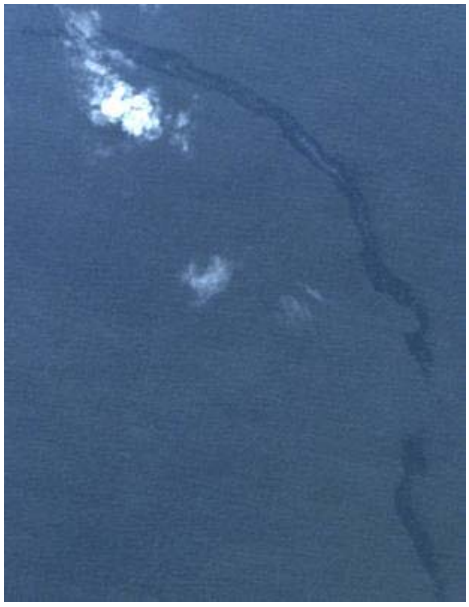

***Fig.26-b. Oil slick at southern coast of Mindoro Island (Date: 2007/11/09)***

d. Date: 23 November 2006, Location: South Coast of Mindoro Island.

Observed oceanic features were natural films at west coast of San Jose and front at south coast of San Jose (upper left part of image). Wave fronts on southeastward direction at northern part and southwest direction at southern part area. Ocean condition was favorable for oceanic feature observation. Current direction was on westward direction. Wind speed about 4.2-4.4 m/s. Wave height about 0.8-1 m.

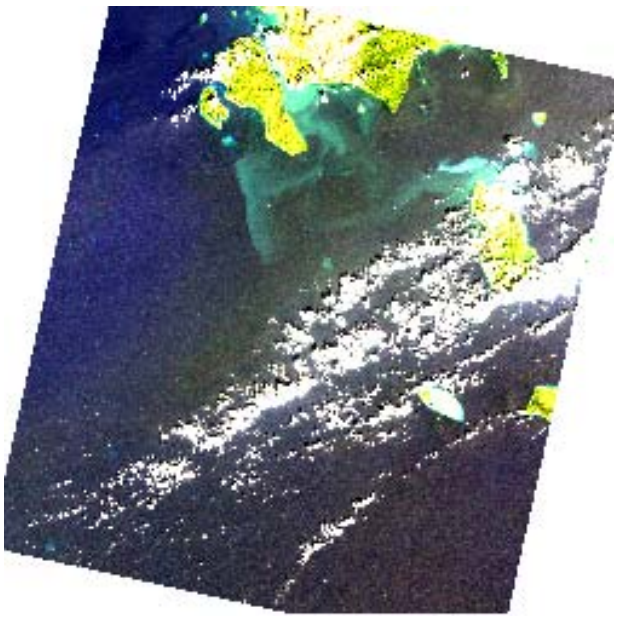

***Fig.27. ALOS AVNIR-2 Image on 2006/11/23 over South of Mindoro Island 3-1-3. MODIS Image***

The observation of Modis image over south of Mindoro strait during June – August 2007 shows that maximum chlorophyll-a distributions were distributed as patches at south west coast of Mindoro Island, northeast coast of Palawan Island,  and northwest coast of Panay Island. During September –

December 2007, maximum distribution areas of chlorophyll-a were intensified, which highest concentration occurred on December 2007. From the end of October, maximum distribution area enlarged from northeast coast of Palawan Island to northwest coast of Panay Island. On November, maximum chlorophyll-a area was intensified along west coast of Mindoro Island. Furthermore, the maximum area at southwest coast of Mindoro, which observed earlier, moved further to south of Mindoro Strait.

Oceanic features, such as eddies, have been observed on MODIS image data over coast of Mindoro Island during June-December 2007. Eddy will cause chlorophyll-a area on curvilinear shape resemble to eddy's shape on image. Eddy-like features were observed frequently at W/SW/S coast of Mindoro Island, NW/NE/W/SW coast of Panay Island, and northeast coast of Palawan Island during September – December period. This phenomenon possibly related with the occurrence of northward and southward flow current at surface (geostrophic current from SSALTO DUACS Products) and strong southward flow current from 200 m to bottom beginning round mid-September recorded on ADCP data (Sprintall, 2007).

3-2. Mindanao Sea

3-2-1. ALOS PALSAR Image

a. Date: 17 January 2007, Time: 14:30:11 UTC, Location: South Coast of Negros Island.

Observed oceanic features were rain patches and natural films at south west coast of Negros Island and coast of Dipolog, Mindanao Island. Weather and ocean condition were possibly strong wind and high waves marked by random black and white pixels. Current direction was on westward direction. Wind speed about 6.4-6.8 m/s. Wave height about 1.6-1.8 m.

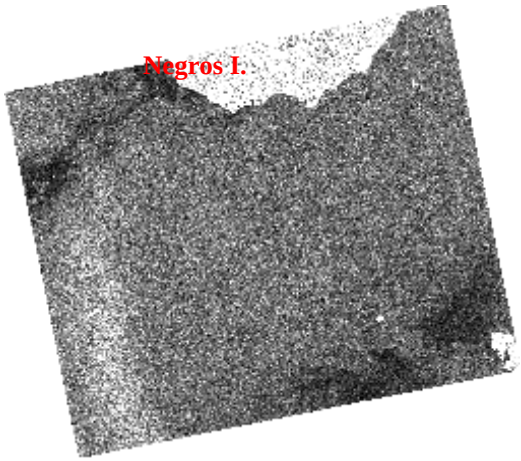


***Fig.28. ALOS PALSAR Image over south coast of Negros Island (Date: 2007/01/17, Time: 14:30:11 UTC)***

b. Date: 3 October 2007, Time: 02:02:59 UTC, Location: South Coast of Negros Island.

No obvious oceanic feature has been observed on image. Weather and ocean condition were unfavorable for oceanic feature detection. Current direction was on west and northwestward direction. Wind speed about 4-6 m/s. Wave height about 1.4-1.8 m.

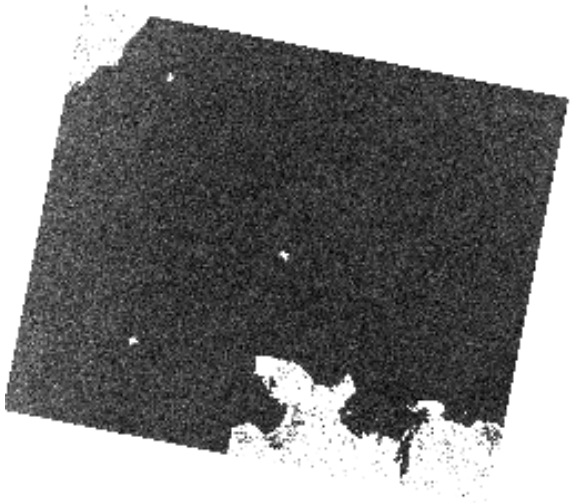

***Fig.29. ALOS PALSAR Image over south coast of Negros Island (Date: 2007/10/03, Time: 02:02:59 UTC)***

c. Date: 20 October 2007, Time: 14:29:43 UTC, Location: Northwest Coast of Dipolog, Mindanao Island.

No obvious oceanic feature has been observed on image. Weather and ocean condition were possibly strong wind marked by random black and white pixels. Current direction was on southwestward direction. Wind speed about 3-4 m/s. Wave height about 0.6-0.8 m.

***Fig.30. ALOS PALSAR Image over Dipolog Strait (Date: 2007/10/20, Time: 14:29:43 UTC)***

d. Date: 20 October 2007, Time: 14:29:51 UTC, Location: south coast of Negros Island.

Observed oceanic features were natural film, front line (bottom left part of image), and rain patches (upper-middle part of image). Weather and ocean condition were unfavorable for oceanic feature detection due to strong wind. Current direction was on west and southwestward direction. Wind speed about 2.5-3.5 m/s. Wave height about 0.6-1 m.

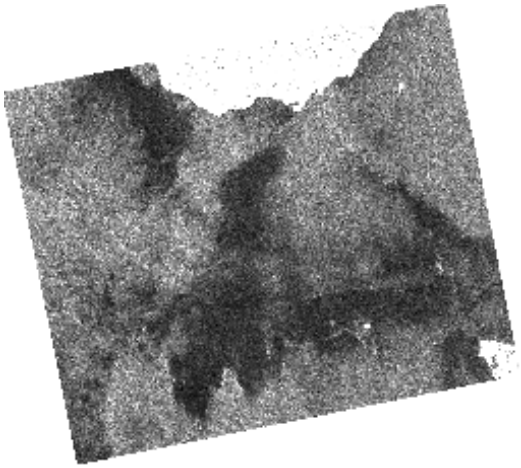

***Fig.31. ALOS PALSAR Image over south coast of Negros Island (Date: 2007/10/20, Time: 14:29:51 UTC)***

3-2-2.
oceanic feature detection. Current direction was on west and southwestward direction. Wind speed about 3.5-4.5 m/s. Wave height about 1.2-1.6 m.

ALOS AVNIR-2 Image

a. Date: 5 November 2007, Location: Dipolog Strait.

Observed oceanic features were non linier internal waves propagated on southeast direction at coast off Dipolog, Mindanao (bottom left part of image), front between two different currents at coast off Negros and Mindanao (middle-upper part). Wave fronts on southeast direction. Ocean condition was favorable for

Negros

***Fig.32. ALOS AVNIR-2 Image on 2007/11/5, over Dipolog Strait***

***Fig.33-a. front between two different currents at coast off Negros and Mindanao (middle-upper part of view image, date: 2007/11/5)***

***Fig.33-b. Non linier internal waves on southeast direction at coast off Dipolog, Mindanao (bottom left part of view image, date: 2007/11/5)***

b. Date: 17 April 2007, Location: Dipolog Strait.

Observed oceanic features were oil slicks (upper and bottom left part of image) and a packet of non linier internal waves propagated on south west direction at coast of Dapitan, and west coast of Dipolog, Mindanao Island. Oil slicks and swarm of natural films at coast of Dipolog (bottom left). Wave fronts at coast off Dipolog on southeast and south westward direction. Ocean condition was favorable for oceanic feature observation. Current direction was on west and southeastward direction. Wind speed about 1.4-1.6 m/s. Wave height about 0.5 m.

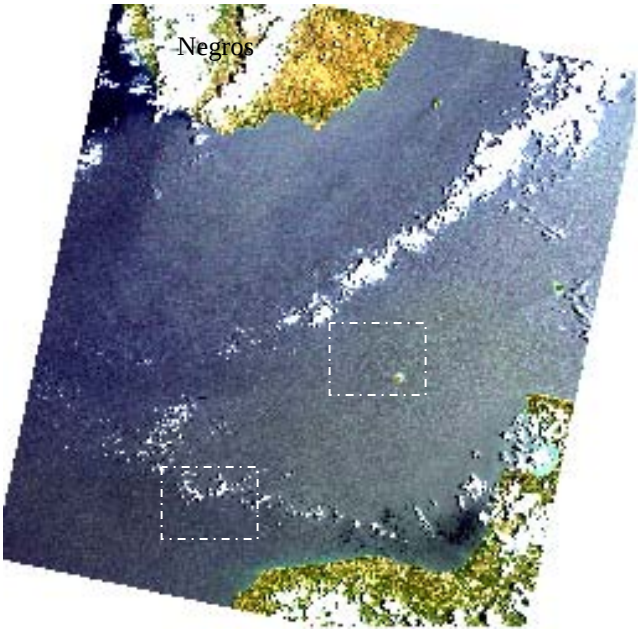


***Fig.34. ALOS AVNIR-2 on 2007/04/17 over Dipolog Strait***

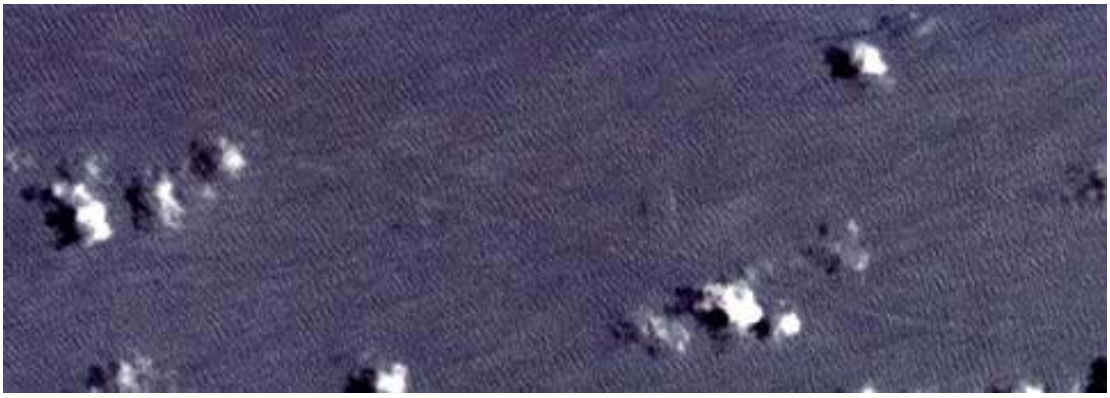

***Fig.35. Non linier internal waves on southwestward direction at northern coast of Dipolog, Mindanao Island (right bottom part of view image, date: 2007/04/17)***

c. Date: 2007/06/02, Location: Coast off Negros and Mindanao Island.

Observed oceanic features were natural films, eddy at southeast coast of Mindanao (upper left part on image), and internal waves at south coast of Negros propagated on southeast direction, and at east coast of Dipolog propagated on northward direction. Ocean condition was favorable for oceanic feature observation. Current direction was on south and southwestward direction. Wind speed about 1.2-1.6 m/s. Wave height about 0.5 m.

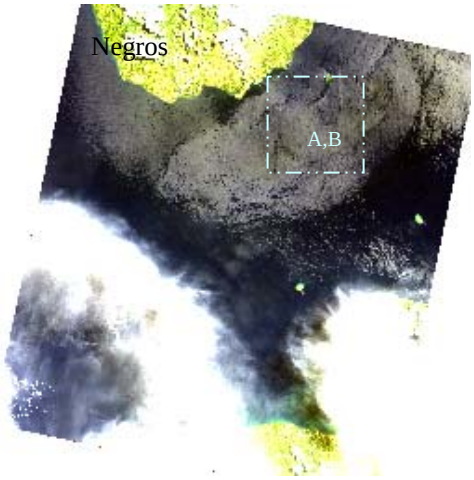


*Fig.36. ALOS AVNIR-2 Image on 2007/06/02 over Dipolog Strait*

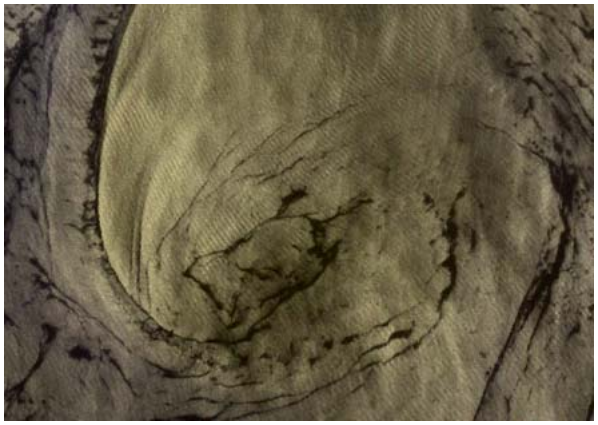

*Fig.37-a. Eddy at southeast coast of Negros (upper right part on view image, date: 2007/06/02)*

*Fig.37-b. Internal waves on southeastward direction at south coast of Negros (upper right of view image, date: 2007/06/02)*

3-2-3. MODIS Image

Maximum distribution of Chlorophyll A areas at Dipolog Strait and Mindanao Sea retrieved from Modis image during June-December 2007 were distributed along coast of Sindangan, Dipolog, Ozamiz and Cagayan de Oro, Mindanao Island. During July to August, the maximum area near coast of Dipolog was intensified and distributed until coast of Siaton, south of Negros Island. During September to October, the maximum distribution at all areas were intensified (>1). The highest distribution areas were observed during November-December period, when maximum Chlorophyll areas were distributed along west to north coast of Mindanao Island and along south coast of Negros.

The observation of oceanic features on MODIS image data over coast of Dipolog Strait during June-December 2007 shows that eddy-like feature at W/NW/N/E coast of Dipolog, southwest coast of Negros Island and north coast of Cagayan de Oro. Eddies were occurred possibly due to reversal current flow at Dipolog Strait, where surface flow is recorded on ADCP toward the west and subsurface flow to eastward direction (Sprintall, 2008). The occurrences of Eddy were consistent with strong 4-6 week periodicity of surface and subsurface current observed on ADCP data.

3-3. Surigao Strait

3-3-1. ALOS PALSAR Image

a. Date: 19 April 2007, time: 02:04:54 UTC, location: Mindanao Sea and Surigao Strait.
Observed oceanic features were oil slicks, natural films, low wind area covered by island, and rain patches at Dipolog Strait, Mindanao Sea, coast of Cebu and Bohol Island. Two packets of non linier internal waves were observed at west coast of Surigao propagated on southeast direction. Others packets at northwest coast of Surigao were propagated on northwest direction. Ocean condition was favorable for oceanic feature observation. Current direction was on west and southwestward direction. Wind speed about 2.8-3.6 m/s. Wave height about 0.6-0.8 m.

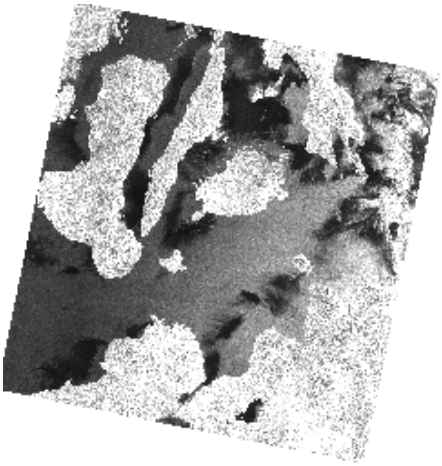

***Fig.38. ALOS PALSAR Image over coast of Negros, Cebu and Bohol Island (Date: 2007/04/19, Time: 02:04:54 UTC)***

***Fig.39. Packets of non linier internal waves were observed at coast of Surigao (Upper right of view image, Date: 2007/04/19, Time: 02:04:54 UTC)***

b. Date: 17 October 2007, Time: 14:19:29 UTC, Location: Southeast Coast of Leyte Island.

Observed oceanic features were rain patches at east coast of Leyte, and front at coast of Dinagat. Ocean condition was unfavorable for oceanic feature due to strong wind. Current direction was on northward direction. Wind speed about 6-7 m/s. Wave height about 1.2-1.4 m.

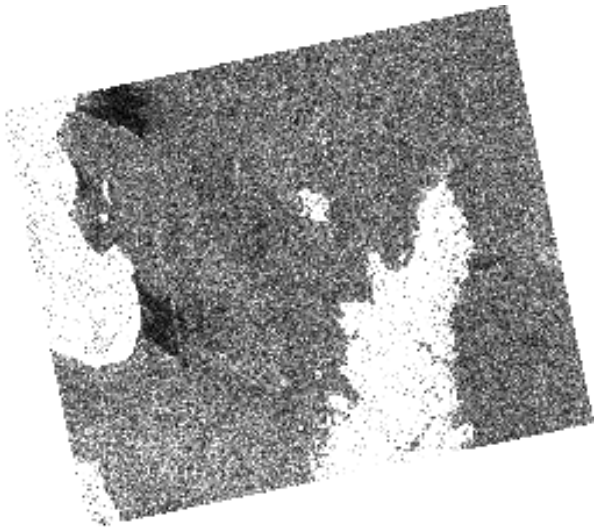

***Fig.40. ALOS PALSAR Image over southeast coast of Leyte Island (Date: 2007/10/27, Time: 14:19:29 UTC).***

c. Date: 17 October 2007, time: 14:19:21 UTC, location: coast of Surigao.

Observed oceanic features were rain patches at east coast of Leyte, strike lines of wave fronts (middle right part of image) and low wind area covered by island. Ocean condition was unfavorable for oceanic feature due to strong wind. urrent direction on southeastward direction. Wind speed about 4-5 m/s. Wave height about 0.8-1 m.

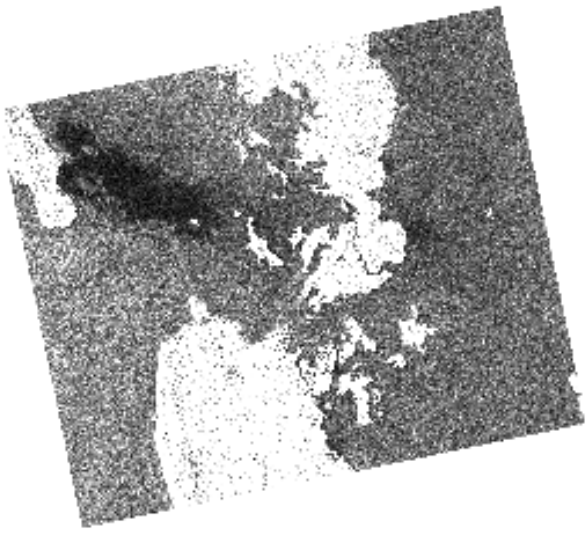

***Fig.41. ALOS PALSAR Image over southeast coast of Leyte Island (Date: 2007/10/27, Time: 14:19:21 UTC).***

3-3-2. ALOS AVNIR-2 Image

a. Date: 11 May 2007, Location: Southeast Coast of Leyte Island.

Observed oceanic features were packets of non linier internal waves associated by slicks propagated on southeast to eastward direction at southeast coast of Leyte Island (upper left, middle and upper right part of image), and a packet of internal waves at coast of Mayorga, southeast of Leyte Island propagated on southwest direction. Others packets were observed at east coast of Homonhon Island, southeast part of Leyte Island, propagated on southwest direction. Dark feature of low wind areas near location of packets of internal waves at southeast coast of Leyte Island (middle part), natural films at southeast coast of Leyte Island (upper left) and east coast of Dinagat Island (bottom right), and front line of two different currents at west coast of Dinagat Island (bottom left). Some internal wave features were associated with natural films at southeast coast of Leyte Island (upper left and middle) suggest the occurrence of upwelling area. Ocean condition was favorable for oceanic feature observation. Current direction was on northwestward direction. Wind speed about 3.5-4 m/s. Wave height about 0.9-1 m.

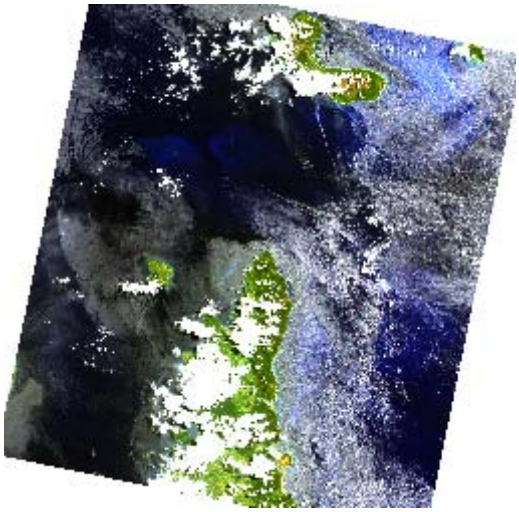

*Fig.42. ALOS AVNIR-2 on 2007/05/11 over southeast coast of Leyte Island.*

*Fig.43-a. Internal waves on southeastward direction at southeast coast of Leyte Island (upper left part of view image, date: 2007/05/11)*

*Fig.43-b. Internal waves on southeastward direction at south coast of Leyte Island (upper right of view image, date: 2007/05/11)*

b. Date: 11 May 2007, Location: Southeast of Leyte Island.

Observed oceanic features were front, natural films and oil slick at east coast of Anilao, Leyte Island, packets of non linier internal waves on southeastward direction at south coast of Leyte Island, south coast of Maasin, Leyte Island, and NLIW on southwestward direction at east coast of Surigao, eddy at northeast of Surigao, Mindanao, and low wind area covered by island at east coast of Surigao. Oil seepage/slicks from oil rigs at south coast of Dinagat (bottom right part of image. Ocean condition was favorable for oceanic feature observation. Current direction was on northwestward direction. Wind speed about 3.5-4 m/s. Wave height about 0.9-1 m.

***Fig.44. ALOS AVNIR-2 on 2007/05/11 over Southeast Coast of Leyte Island.***

***Fig.45-a. Front at east coast of Anilao, Leyte Island (middle to upper left part of view image, date: 2007/05/11)***

***Fig.45-b. Internal waves at south coast of Leyte Island (middle part of view image, date: 2007/05/11)***

***Fig.45-c. Internal waves at south coast of Maasin, Leyte Island (bottom left part of view image, date: 2007/05/11)***

***Fig.45-d. Eddy at northeast of Surigao, Mindanao Island (bottom right part of view image, date: 2007/05/11)***

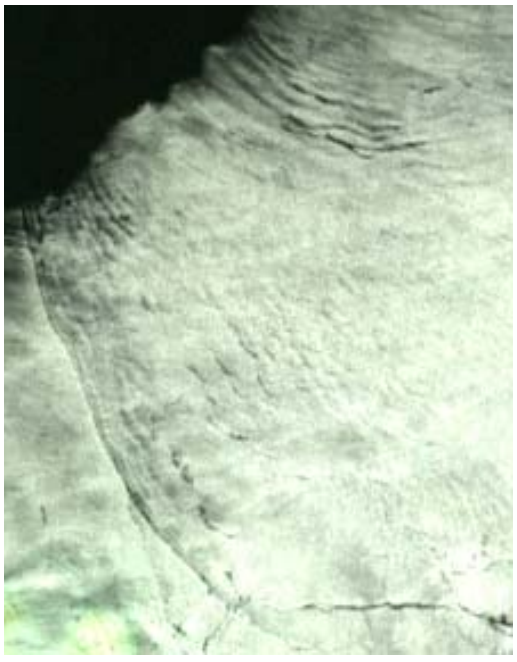

***Fig.45-e. Non linier internal waves on southwestward direction at east coast of Surigao (bottom right part of view image, date: 2007/05/11)***

***Fig.45-f. Non linier internal waves associated with slicks at east part of Surigao (bottom right part of image, date: 2007/05/11)***

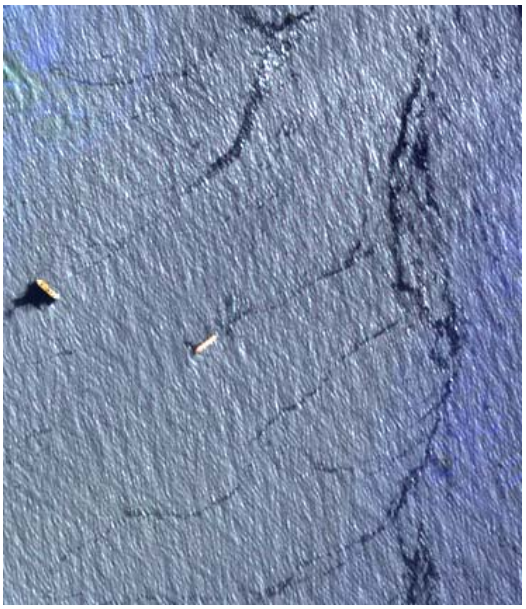

***Fig.45-g. Oil slicks from oil rigs at south coast of Dinagat (bottom right part of view image, date: 2007/05/11)***

c. Date: 8 November 2006, Location: Southeast of Leyte Island.

Observed oceanic features were natural films at east and west coast of Dinagat, eddies, shallow reefs and non linier internal waves at southeast coast of Leyte Island, and fronts at east coast of Anilao. Ocean condition was favorable for oceanic feature observation. Current direction was on west and southwestward direction. Wind speed about 3.5-4.5 m/s. Wave height about 0.8-0.9 m.

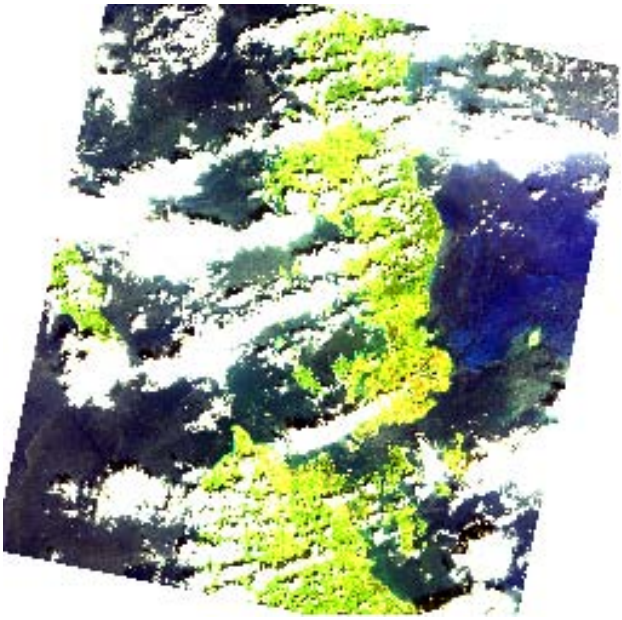

***Fig.46. ALOS AVNIR-2 Image on 2006/11/08 over southeast coast of Leyte Island.***

***Fig.47-a. Eddy at southeast coast of Leyte Island (middle right of view image, date: 2006/11/08)***

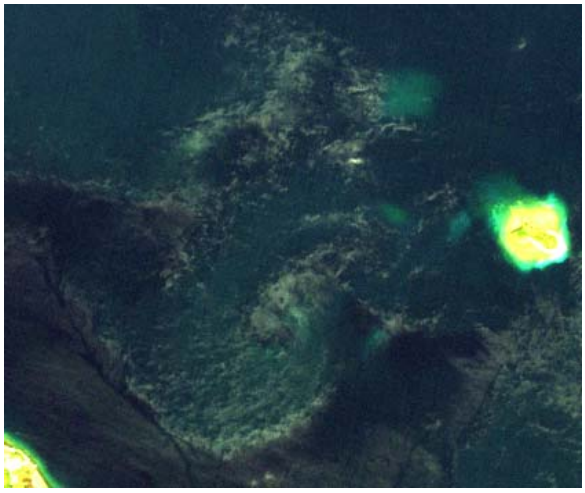

***Fig.47-b. Front at east coast of Anilao, southeast of Leyte Island (middle left of view image, date: 2006/11/08)***

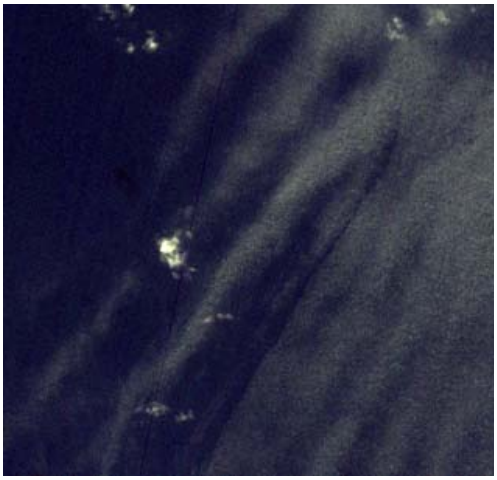

***Fig.47-c. Internal waves at southeast coast of Leyte Island (upper left of view image, date: 2006/11/08)***

d. Date: 8 November 2006, Location: Southeast of Leyte Island.

Observed oceanic features were packets of internal waves on on northwestward direction at east coast of Leyte Island, southwestward direction at coast of Surigao, on westward direction at west coast of Surigao, and southeast direction at southwest coast of Surigao, fronts at west coast of Surigao, and natural films at east and west coast of Surigao. Ocean condition was favorable for oceanic feature observation. Current direction was on west and southwestward direction. Wind speed about 3.5-4.5 m/s. Wave height about 0.8-0.9 m.

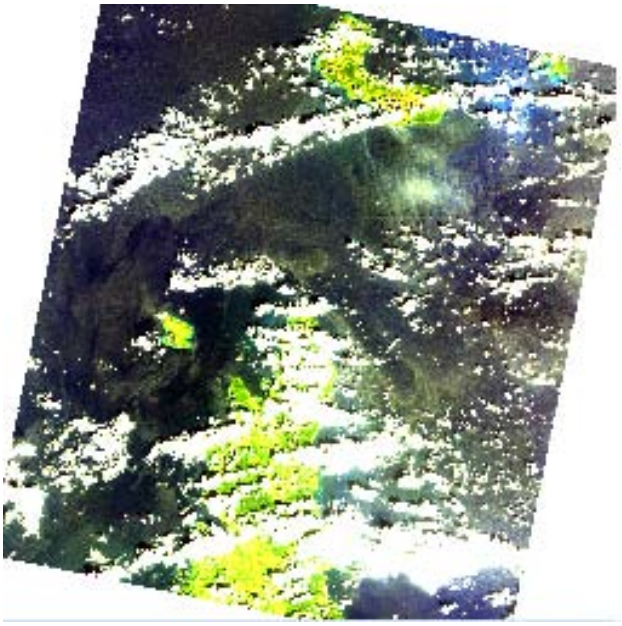

***Fig.48. ALOS AVNIR-2 Image on 2006/11/08 over east and southeast coast of Leyte Island***

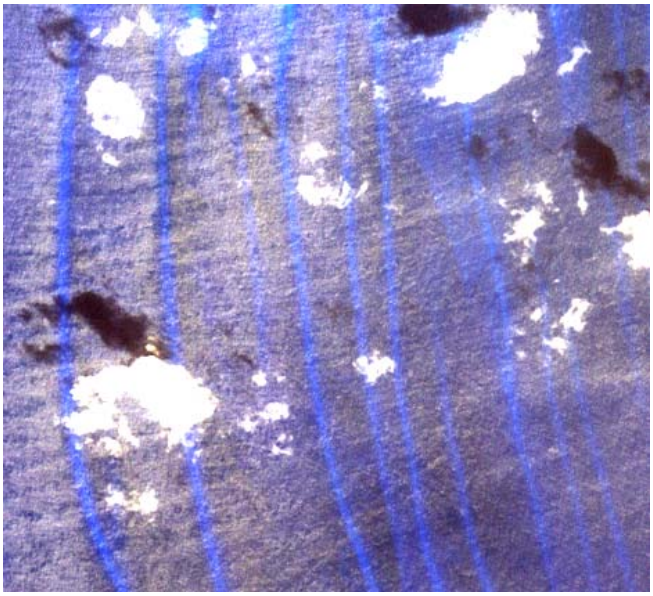

***Fig.49-a. Internal waves on southwest direction at east coast of Leyte Island (upper right part of view image, date: 2006/11/08)***

***Fig.49-b. Front at east coast of Leyte Island (upper right of view image, date: 2006/11/08)***

***Fig.49-c. Internal waves southeast coast of Leyte Island (middle left of view image, date: 2006/11/08)***

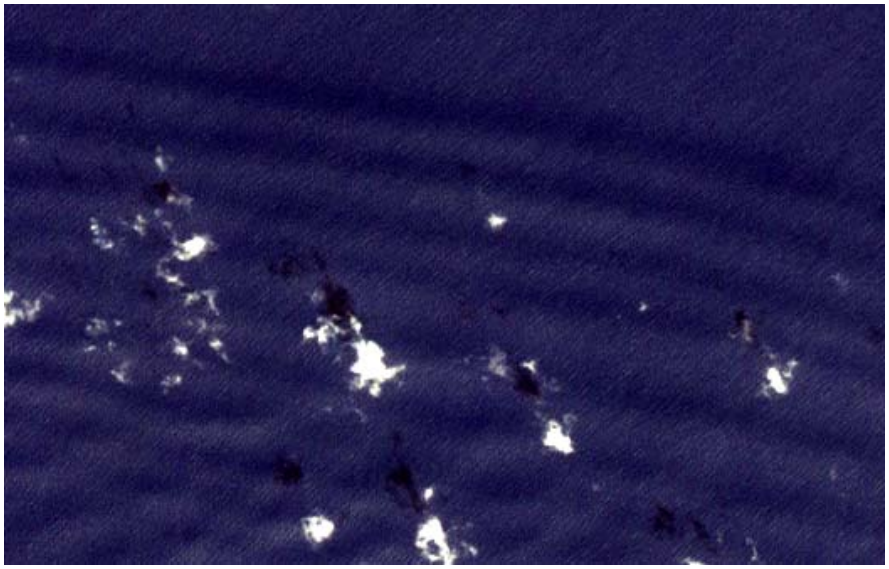

***Fig.49-d. Internal waves east coast of Leyte Island (upper left of view image, date: 2006/11/08)***

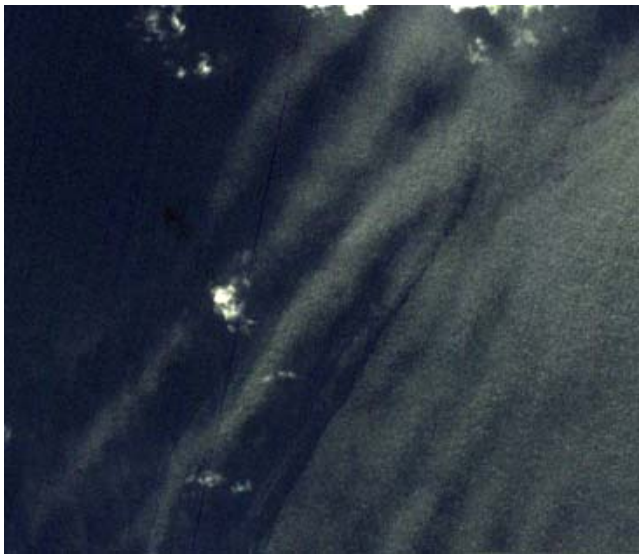

***Fig.49-e. Internal waves on westward direction at west coast of Surigao (bottom left of view image, date: 2006/11/08)***

3-3-3. MODIS Image

The observation of Modis one day composite image over coast of Surigao during June – December 2007 shows maximum chlorophyll A distributions were observed from coast of Cabadbaran, southwest part of Surigao, into northeast coast of Surigao. At western part, maximum area was shown at north and southeast coast of Bohol Island. On June to July period, these areas were shown as patches. From August, the maximum area at southwest part was intensified (>1) and spread into west part of Surigao. At the end of november, maximum chlorophyll-a area was distributed from southwest coast of Surigao

into southeast coast of Bohol. The largest maximum area was observed on December, where the highest chlorophyll-a concentration was located at southwest coast of Surigao.

The oceanic feature observation on MODIS image during June – December 2007 shows that coast Surigao is the most active area for oceanic features compare to other study areas at south of Mindoro Strait and Dipolog Strait. During this period, eddy-like features were observed at NE/NW/W/SW coast of Surigao and E/SE/S coast of Bohol Island.

**RESULTS**

1. Physical structure of the water off Panay

From the satellite, data including the sea surface roughness by SAR, the chlorophyll-a concentration and the sea surface temperature by MODIS, NCEP wind vectors, and the current measurements, we could discuss the mechanism of current system in the western off of the Panay Island.

The N-wind was dominant from the middle of June 2007 and the N-wind generated the Ekman current toward the North. The ADCP record showed the change of current north-ward from the middle of June 2007. As the wind speed was not so high, the surface roughness observed by SAR exhibited the north-ward current and the upwelling in the northern side of islands.

2. Biological contribution to the water surface

The record of ADCP in the Philippine Archipelagoes by Dr. Janet Sprintall captured the change of currents in the surface layer up to 150 m and in the deeper water at the South Mindoro.

The chlorophyll-a distribution observed by MODIS showed the water body from the Sibuyan Sea to the northern end of the Sulu Sea with a high chlorophyll-a concentration under the NE wind season. The water from the central part of the Sulu Sea intruded the west coast of the Panay Island with a low chlorophyll-a concentration.

From these background, we have conducted the in-situ measurement off the western coast of the Panay Island in February of 2008 jointly with the Dr. Cesar Villanoy of the Philippine University to discuss the water structure.

Although it was difficult to identify the water structure by the surface roughness observed by SAR because of the high speed wind, it was possible to find the high chlorophyll-a concentration in the water entrained from the Sulu Sea and the intrusion of the water from the central part of the Sulu Sea. This structure of the water column was confirmed by the nutrients profiles at the station, where the ADCP mooring was deployed, and at the station between the ADCP position and the coast. The nutrients exhibited the clear difference of the water body with a silicate rich water in the water from the Sibuyan Sea and the silicate depleted water in the water from the central part of the Sulu Sea.

3. Mechanism of oceanic phenomena

3-1. Mindoro – Panay Strait

The observation of ALOS PALSAR, AVNIR-2 and MODIS images over Mindoro – Panay Strait, Mindanao Sea and Surigao Strait shows that oceanic features, such as oil slick, internal wave, natural film, wind shear, front, can be observed in these areas throughout year. In Mindoro – Panay Strait, non linier internal waves were observed at south coast of Mindoro Island, northeast coast of Palawan Island, and southwest coast of San Jose, Panay Island. The internal waves feature shows in rank-order wave height suggesting non linier internal waves were generated due to bathymetry effect. The internal waves were propagated within directions of geostrophic currents retrieved from SSALTO/DUACS data.

Oil slick and natural films were observed at west coast of Mindoro Island, west coast of San Jose, Mindoro Island, east coast of Palawan Island, west of Iloilo, and west coast of Panay Island. Natural film area can be associated with blooming of plankton and upwelling area, which can be detected under favorable wind condition below 3 m/s. The occurrence of natural film also can be associated with eddy feature, observed in west coast of San Jose, Mindoro Island and northwest coast of Panay Island. The distribution of chlorophyll-a retrieved from MODIS image was observed for eddy feature. Eddy will cause chlorophyll-a area on curvilinear shape resemble to eddy's shape on image. On MODIS image, eddy-like features were observed frequently at W/SW/S coast of Mindoro Island, NW/NE/W/SW coast of Panay Island, and northeast coast of Palawan Island during September – December period. Eddies feature at this area possibly generated by the occurrence of northward and southward flow current at surface, showed in geostrophic currents (SSALTO DUACS Products), and strong reversal southward flow current from 200 m to bottom beginning round mid-September recorded on ADCP data (Sprintall, 2007).

Wind shear feature is observed at west coast of San Jose, Mindoro Island on 23 February 2007 during winter monsoon when NW winds blow over Mindoro Island.

Maximum chlorophyll-a areas retrieved from MODIS image during June – August 2007 were distributed as patches at south west coast of Mindoro Island, northeast coast of Palawan Island, and northwest coast of Panay Island. During September – December 2007, maximum distribution areas of chlorophyll-a were intensified, which highest concentration occurred on December 2007, which possibly relate to strong meridional flow current from mid of September to December shown in ADCP data (Sprintall, 2008).

3-2. Mindanao Sea

Oceanic features have been detected in Mindanao Sea and adjacent waters. Internal wave features have been located at coast of Dipolog, Dapitan, and south coast of Mindanao. At coast of Dipolog, direction of internal wave on 5 November 2007 was on southeast direction. Meanwhile geostrophic current map shows current direction at coast of Dipolog was on west to southwest direction and direction at west coast of Panay Island was on southeastward. This phenomenon suggests the internal waves were propagated from Panay Strait into Mindanao Sea. Internal wave direction was fit to subsurface current recorded from Dipolog mooring during July-December 2007, which was on eastward direction, while surface flow direction was on the west (Sprintall, 2008). The internal waves at coast of Dipolog on 17 April 2007 was on southwest direction, suggested this packet were propagated from Mindanao Sea. All

of internal waves feature shows in rank-order wave height suggesting non linier internal waves were generated due to bathymetry effect.

The different direction of inflow and outflow current at Mindanao Sea also shown in Fig. 19, a packet of internal waves at east coast of Dipolog was propagated into northward direction, whereas other packet stranded near southeast coast of Negros Island was propagated on southeast. An eddy with counter clockwise direction was observed between these packets suggesting the meeting point of two currents with different direction.

The observation of MODIS image data over coast of Dipolog Strait during June-December 2007 shows eddy-like feature at W/NW/N/E coast of Dipolog, southwest coast of Negros Island and north coast of Cagayan de Oro, Mindanao Island. The occurrences of eddy during this period were consistent with strong 4-6 week periodicity of surface and subsurface current observed on ADCP data.

Maximum distribution of chlorophyll-a areas at Dipolog Strait and Mindanao Sea were distributed along coast of Sindangan, Dipolog, Ozamiz and Cagayan de Oro. During July to August, the maximum area near coast of Dipolog was intensified and distributed until coast of Siaton, south of Negros Island. During September to October, the maximum distributions at these areas were intensified. The highest distribution areas were observed during November-December period, when maximum chlorophyll-a areas were distributed along west to north coast of Mindanao Island and along south coast of Negros. This condition possibly forced by strong surface flow during northwest monsoon and reversal subsurface current at Dipolog Strait, which lead to upwelling process in this area.

3-3. Surigao Strait

Among other study areas, Surigao Strait was the most active area for oceanic features, such as internal wave, natural film and eddy, possibly due to strong tidal current. Packets of non linier internal waves on PALSAR image (4/19/2007) were observed at west and northwest coast of Surigao on southeast and northwest direction suggests the propagation from Pacific Ocean to Mindanao Sea. On AVNIR image (5/11/2007), packets of internal waves were observed at coast of Mayorga, southeast of Leyte Island propagated on southwest direction. Others packets were observed at east coast of Homonhon Island propagated on southwest direction. This phenomenon suggests the internal waves generated at north and south coast of Homonhon Island before it reached to Surigao Strait, then Mindanao Sea. All of internal waves feature shows in rank-order wave height suggesting non linier internal waves were generated due to bathymetry effect.

Eddy on clockwise direction was observed at northeast of Surigao, Mindanao Island, possibly generated by meeting of two currents flow from south coast of Dinagat Island and southeast coast of Leyte Island.

The observation of Modis one day composite image over coast of Surigao during June – December 2007 shows maximum chlorophyll-a distributions were observed from coast of Cabadbaran, southwest of Surigao, into northeast coast of Surigao. At western part, maximum area was distributed at north and southeast coast of Bohol Island. On June to July period, these areas were shown as patches. From August, the maximum area at southwest part was intensified and spread into west part of Surigao. At the end of November, maximum chlorophyll area was distributed from southwest coast of Surigao into southeast coast of Bohol. The largest maximum area was observed on December, where the highest chlorophyll-a concentration was located at southwest coast of Surigao, This condition possibly forced

by strong surface flow during northwest monsoon and reversal subsurface current at Dipolog Strait, which lead to upwelling process in this area.

## IMPACT/APPLICATIONS

1. Physical structure of the water off Panay

The current vectors observed by the ADCP mooring give us the very interesting structure in this region. The satellite measurements are enforced by these in-situ measurements.

2. Biological contribution to the water surface

The relationship between the surface roughness observed by the SAR and the chlorophyll-a concentration was studied. This study made clear the limitation of sea surface roughness by the wind speed of the region. In the following study, the contribution of the biological film to the surface roughness will give us more interesting knowledge.

3. Mechanism of oceanic phenomena

Oceanic features have been observed in ALOS PALSAR and AVNIR images over Philippine during northwest monsoon. More investigation is needed for the observation during summer monsoon on image and oceanic data. Automatic oceanic feature on image over Philippine waters using coupled wavelet-neural network is proposed to enhance the oceanic feature observation method.

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